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MECHANISM

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MECHANISM

INSTRUCTION PAPER

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MECHANISM

The study of mechanism is the study of the laws that govern the motions and forces in machinery. Pure mechanism deals only with the amount and kind of motions, without regard to the forces transmitted, and in this instruction paper only this branch of the subject will be considered. That is, we shall study how to proportion the parts to get the proper motions. Knowing this, the principles of machine design and strength of materials will teach us how large the parts must be to stand the stresses which come upon them.

A Mechanism is a group of parts so shaped and arranged that a definite motion of one part will give other definite motions to the other parts.

A Machine is a combination of mechanisms each of which may be doing a different kind of work, but the whole combination of mechanisms working together accomplishes some desired result. Take for example, a metal planer; the result which is to be accomplished is the planing of a piece of metal, but in order to do this, several auxiliary results must be accomplished. The table or platen, to which the metal is fastened must be moved back and forth, the tool must be fed forward after each chip has been cut, and various other motions produced. There are certain pieces in the planer whose sole work is the moving of the platen, and all these pieces taken together form one mechanism; in like manner, there are certain parts whose sole work is feeding the tool forward each time, and all these parts taken together form another mechanism. All the mechanisms when brought together form the machine.

MOTION.

An object which is changing its position is said to be in motion and an object which is not changing its position is at rest.

Absolute and Relative Motion. If a man is moving along in a sail boat without changing his position in the boat, both man and boat have what is usually spoken of as absolute motion, that

is, they are both changing their position with respect to the earth and water around them. They both change their position in the same direction and at the same rate however, so that they are at rest with respect to each other. If now, the man should start to walk forward in the boat, he would change his position with respect to surrounding objects faster than the boat and he would have motion relative to the boat. We thus have two kinds of motion, absolute and relative; absolute motion being the motion of a body with respect to some fixed object, and relative motion being the motion of one moving body with respect to another moving body.

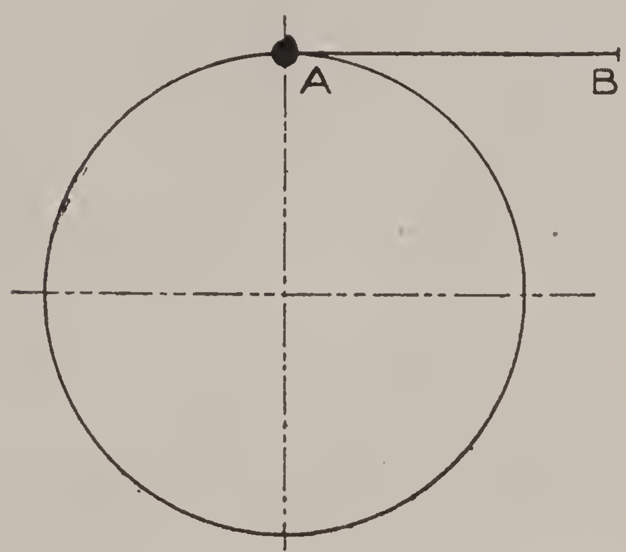


Fig. 1.

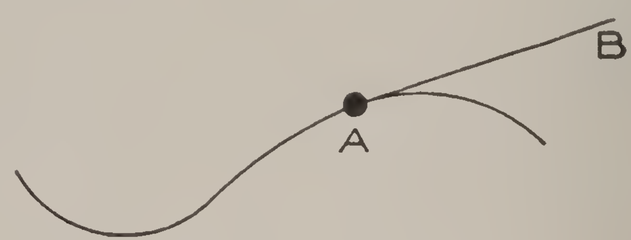


Fig. 2.

Since every object has more or less size and therefore can not be represented on paper as readily as can some particular point or line in the body, as far as possible in our study of the motions of bodies we shall consider points and lines, in place of the bodies themselves.

Velocity is the rate of motion. If a bullet travels through the air at the rate of one hundred feet in a second, it has a velocity of one hundred feet per second.

Direction of Motion. A point may have motion in a straight line, in a circle, or in any other curve. The tendency of any body which is in motion is to continue to move in a straight line unless caused to leave that path by some force applied to the body. The direction of the straight line in which a point is moving is called the direction of motion of the point. If an object is traveling in a circle, the direction of its motion at any given instant is the straight line tangent to the circle at the point where the object

is at the given instant. For example, if the point A, Fig. 1, is moving around the circle, the direction of its motion, when in the position shown, is the line AB. In the same way in Fig. 2, if the point A is moving in the curved path, its direction when in the position indicated is the line AB.

By choosing a convenient scale, as one inch equals one foot, or one inch equals ten feet, etc., depending upon how large the velocities are with which we have to deal, the line may be drawn of a length that will represent the velocity of the point A. Suppose the circle, Fig. 1, to have a circumference of ten inches, and suppose the point A to be traveling around the circle at such a speed that it goes around once in five seconds; then, since it travels ten inches in five seconds, it has a velocity of two inches per second. Accordingly, if we draw the line AB two inches long, tangent to the circle at any given position of A, the line AB represents the direction and velocity of A at the instant under consideration. Of course, the direction of motion of a point which is moving in any path other than a straight line is constantly changing, but the direction in which it is moving at a given instant is the direction which it would take if the forces which constrain it to move in the curved path were removed at that instant.

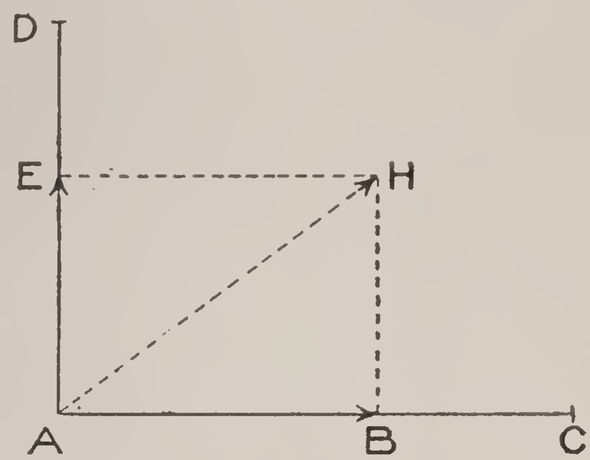


Fig. 3.

Composite Motions. In Fig. 3, let A represent a body lying on a table; suppose AC and AD are strings making a right angle with each other. First, let the string AC be pulled with such force that it will cause A to move one inch in the direction AC, in one second; then A will be at B at the end of a second, the line AB representing the direction and velocity of A when the string AC is pulled. Next, suppose the body to be back in its original position A, and that the string AD is pulled with such force that it will cause A to move $\frac{3}{4}$ of an inch in the direction AD in one second; then at the end of a second A will be at E, the line AE representing the direction and velocity of the body when the string AD is pulled.

Again, suppose both strings to be pulled at the same time, with the same force as before. Then the pull on AC will still cause A to move toward C with a velocity AB, and the pull on AD will cause A to move toward D with a velocity AE, so that at the end of a second the body will be at neither E nor B, but at some point H, whose position is at a distance BH from B, the line BH being equal and parallel to AE. The point H is also at a distance EH from E, the line EH being equal and parallel to AB. In other words, the path over which the body has moved is the line AH, which is the diagonal of a parallelogram whose sides are equal to AB and AE respectively. The lines AB and AE, which represent the velocities caused by the pulls on the respective strings, must be drawn to the same scale, that is, if the pull on AC causes a velocity of one inch per second and

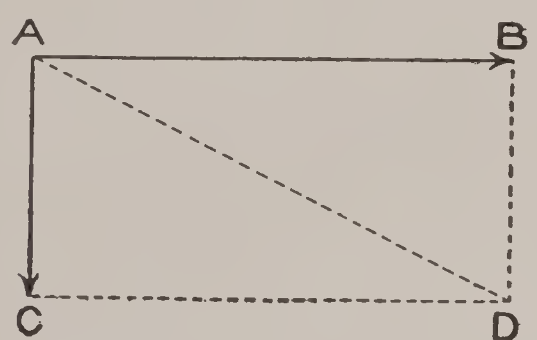


Fig. 4.

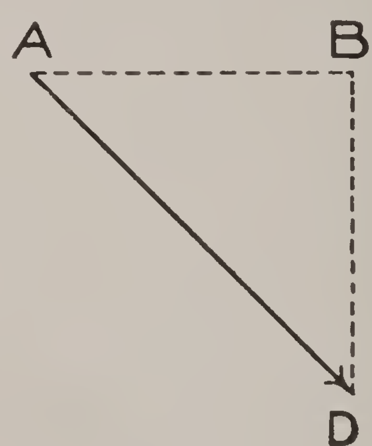


Fig. 5.

the pull on AD causes a velocity of $\frac{3}{4}$ inch per second, AE must be $\frac{3}{4}$ as long as AB.

The velocities AB and AE are called *component velocities*, and the velocity AH the *resultant*.

Let us take another example. Suppose a ball is thrown toward the east with a velocity of ten feet per second, and the wind carries the ball toward the south with a velocity of five feet per second. Let us find graphically how fast and in what direction the ball is actually moving. Using any convenient scale, draw the line AB, Fig. 4, to represent ten feet, and the line AC to represent five feet at the same scale, AC being at right angles to AB, since south is at right angles to east. From C draw CD parallel to AB, and from B draw BD parallel to AC meeting CD at D; then AD, the diagonal of the rectangle thus formed, gives the

direction and the velocity, at the same scale as before, of the actual motion of the ball.

The preceding process is called *composition* of velocities; that is, if we know the velocity of a body in two directions at right angles to each other, we can find from these the real velocity and direction of the motion. Quite as frequently we have given the real direction and velocity and wish to find the velocity parallel and at right angles to some given line. Thus, suppose we know that a ball is moving at a speed of one hundred feet per minute toward the southeast and we wish to know how fast it is moving towards the east. Draw the line AD, Fig. 5, to represent one hundred feet, at a convenient scale; then draw the line AB, making with AD the same angle that a line running southeast makes with a line running east (that is, 45 degrees). From D draw DB perpendicular to AB, meeting AB at B; the length of AB represents, at the same scale at which AD was drawn, the velocity of the ball in an easterly direction, and BD represents its velocity in a southern direction. This is called the *resolution* of velocities, the velocity AD being resolved into two components, one in the direction AB, and one perpendicular to this direction.

*EXAMPLES FOR PRACTICE.

1. If a steamer travels 91,200 feet per hour, what is the velocity in feet per second?

Ans. 25.33 feet.

2. If the piston of an engine moves at the rate of 12.5 feet per second, what is the piston speed in feet per minute?

Ans. 750 feet.

3. A steamer is moving eastward at a speed of 800 feet per minute and the wind and tide carry it north at the rate of 100 feet per minute. Find graphically how fast and in what direction the steamer is actually moving.

Ans. 810 feet per minute.

4. A ball is thrown, with a velocity of 50 feet per second, across a stream 100 feet wide. The wind carries the ball up stream 10 feet per second. How far up stream from the point at which the ball was aimed will it strike? Ans. 20 feet.

*NOTE. Problems 3, 4, 5 and 6 are to be solved graphically.

5. A platform is set up at an angle of 30 degrees with the horizontal, and a weight is allowed to slide down the platform at a speed of ten feet per second. How long will it take the weight to get 10 feet below the point from which it started?

Ans. 2 seconds.

6. The horizontal component of the velocity of a body is 26 feet per minute. If the actual velocity is 52 feet per minute find graphically the vertical component.

Ans. 45 feet per minute (about).

7. A man is on a railway train which is moving at the rate of 25 miles per hour and walks toward the rear of the train at the rate of 88 feet per minute. How fast is the man actually moving?

Ans. 24 miles per hour.

Temporary Center of Revolution. In Fig. 6, let AB represent a bar that forms some part of a mechanism, and suppose that for the moment the end B has a velocity in the direction of and equal to BD, and that the end A has a velocity in the direction of and equal to AC. As the whole rod, for the instant, is moving as if it were revolving about a center, the actual velocities of the various points in the rod are proportional to their distances from the center. To find the center for the case shown, draw the lines AT and BT perpendicular to AC and BD, respectively, until they meet at T, which is the center about which the whole rod may be considered to be revolving. The velocities AC and BD cannot be chosen at random, but must be such that BF is equal to AE; that is, their components in the direction of AB must be equal.

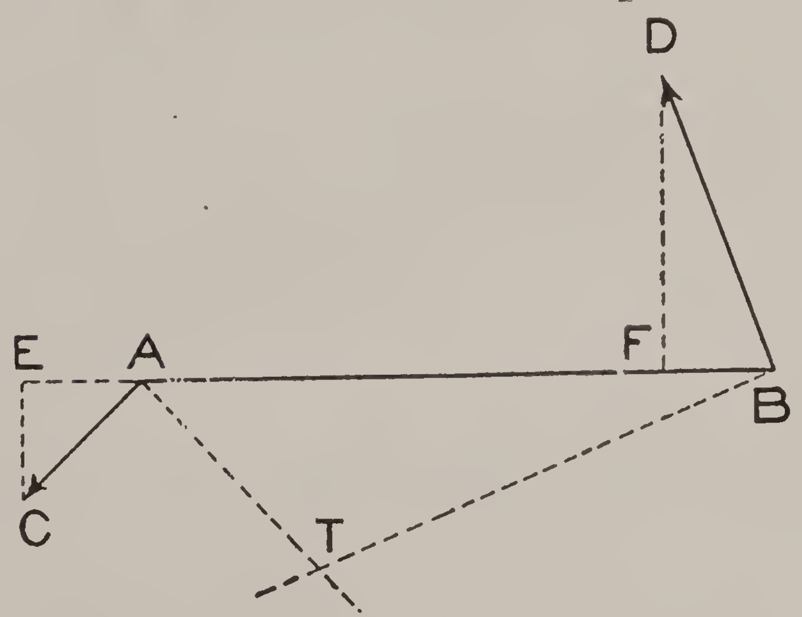


Fig. 6.

REVOLVING BODIES.

One of the most common motions which is found in machinery of all kinds is the motion of revolution, that is, the motion of a

body turning around a center or axis. The axis may pass through the body itself or it may lie entirely outside the body. Fig. 7 is an example of the first case, where the cylinder is revolving about the shaft A, which passes through the center of the cylinder. Fig. 8 is an example of the second case where the block B is revolving about the shaft A.

The speed of revolution of a body is generally described by giving its number of revolutions per minute, which is abbreviated to R. P. M.

We will use the following abbreviations throughout this instruction paper: d=diameter; r=radius or distance of a point from the center about which it is revolving, and π (pronounced Pi)=3.1416.

Let us consider a point C on the circumference of the cylinder in Fig. 7. For every complete revolution of the cylinder the

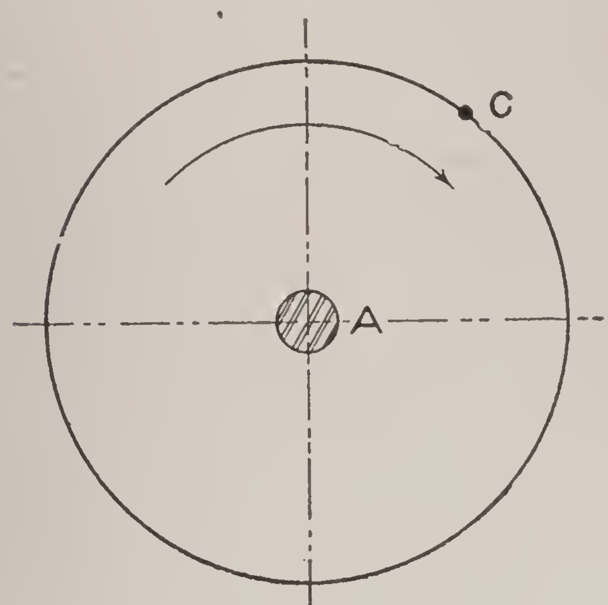


Fig. 7.

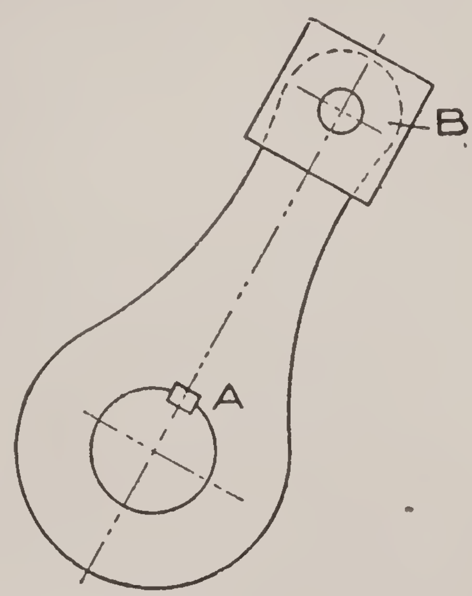


Fig 8.

point C travels through the air a distance equal to the circumference of the cylinder, or, since the circumference of a cylinder is 3.1416 times its diameter, the point C will travel 3.1416 times the diameter of the cylinder. Therefore the actual velocity through the air or **linear velocity** as it is termed, of a point on the circumference of a revolving cylinder is equal to the diameter of cylinder times 3.1416 times the number of revolutions in a unit of time.

If we assume a foot as our unit of distance and a minute as our unit of time, the above principle may be stated as a formula:

$$\text{Linear Velocity} = \pi\, d \text{ times R. P. M.} \qquad (1)$$

$$\text{or `` `` } = 2\,\pi\, r \text{ times R. P. M.} \qquad (2)$$

This will give the linear velocity in feet per minute and to use this formula the diameter or radius must be expressed in feet or fractions of a foot. If d or r is in inches, the linear velocity will be in inches. If linear velocity per second is desired, the number of revolutions per second must be used instead of R. P. M. From this formula we see that the linear velocity varies directly as the diameter or radius, and also directly as the number of revolutions.

The following examples will illustrate the use of the above formula:

If a fly wheel is 10 feet in diameter and makes 75 revolutions per minute, how fast is a point on its circumference moving? Using formula (1),

$$\begin{aligned} \text{Linear Velocity} &= \pi\, d \times \text{R. P. M.} \\ &= 3.1416 \times 10 \times 75. \\ &= 2356.2 \text{ feet per minute.} \end{aligned}$$

Therefore a point on the circumference of the fly wheel is moving at the rate of 2356.2 feet per minute.

Suppose that the center of the block B, Fig. 8, is at a distance of 18 inches from the center of the shaft A and that the arm turns around the shaft 60 times per minute. To find the linear velocity of the center of block B, we must first reduce the 18 inches to feet. Then,

$$\begin{aligned} \text{Linear Velocity} &= 2 \times 3.1416 \times 1.5 \times 60. \\ &= 565.49 \text{ feet per minute.} \end{aligned}$$

The same formula may be used to find the diameter or radius when the linear velocity and revolutions are given, or to find the revolutions when the linear velocity and diameter or radius are given. To do this, substitute the known quantities in the equation and solve by Algebra to find the unknown quantity. Let V = Linear Velocity.

Linear Velocity: $$V = \pi d \times R. P. M.$$

Diameter: $$d = \frac{V}{\pi \times R. P. M.}$$

Revolutions: $$R. P. M. = \frac{V}{\pi d.}$$

EXAMPLES FOR PRACTICE.

1. Find the linear velocity of a point on the rim of a fly wheel making 120 revolutions per minute. Assume fly wheel to be 7 feet in diameter. Ans. 2638.9 feet.

2. How many turns will a 6-foot wheel make while going one mile?

Ans. 280.

3. A locomotive is running at the rate of 40 miles per hour. How many revolutions are the $6\frac{1}{2}$-foot drivers making per minute?
Ans. 172.

4. The drivers of a locomotive are $5\frac{1}{2}$ feet in diameter. The crank pin is twelve inches from the center of the wheel. Find the linear velocity in feet per second of the crank pin if the engine makes 25 miles per hour. Ans. 13.32.

CYLINDERS AND CONES REVOLVING IN CONTACT.

When two cylinders are arranged to revolve upon parallel axes which are at a distance apart just equal to the sum of the radii of the two cylinders, their circumferences will touch along one line, and if both cylinders revolve and we assume that there is no slipping of one surface on the other, the surface velocities of their circumferences must be equal, that is, the linear velocity of any point on the surface of one would be the same as the linear velocity of any point on the surface of the other. Then, if in Fig. 9, we let S equal the surface velocity of the cylinders, C the radius of cylinder A, D the radius of B, M the revolutions per minute of A, and N the revolutions per minute of B, we can obtain the following equations by substituting these values in formula (2):—

$$S = 2\pi C \times M.$$
$$S = 2\pi D \times N.$$

and dividing the first by the second we have:

$$\frac{S}{S} = \frac{2\,\pi\,C \times M}{2\,\pi\,D \times N} \text{ or } 1 = \frac{C\,M}{D\,N}$$

therefore $D\,N = C\,M$ or $D \times N = C \times M$.

According to ratio and proportion in Algebra,

$$\frac{M}{N} = \frac{D}{C} \qquad \textbf{(3)}$$

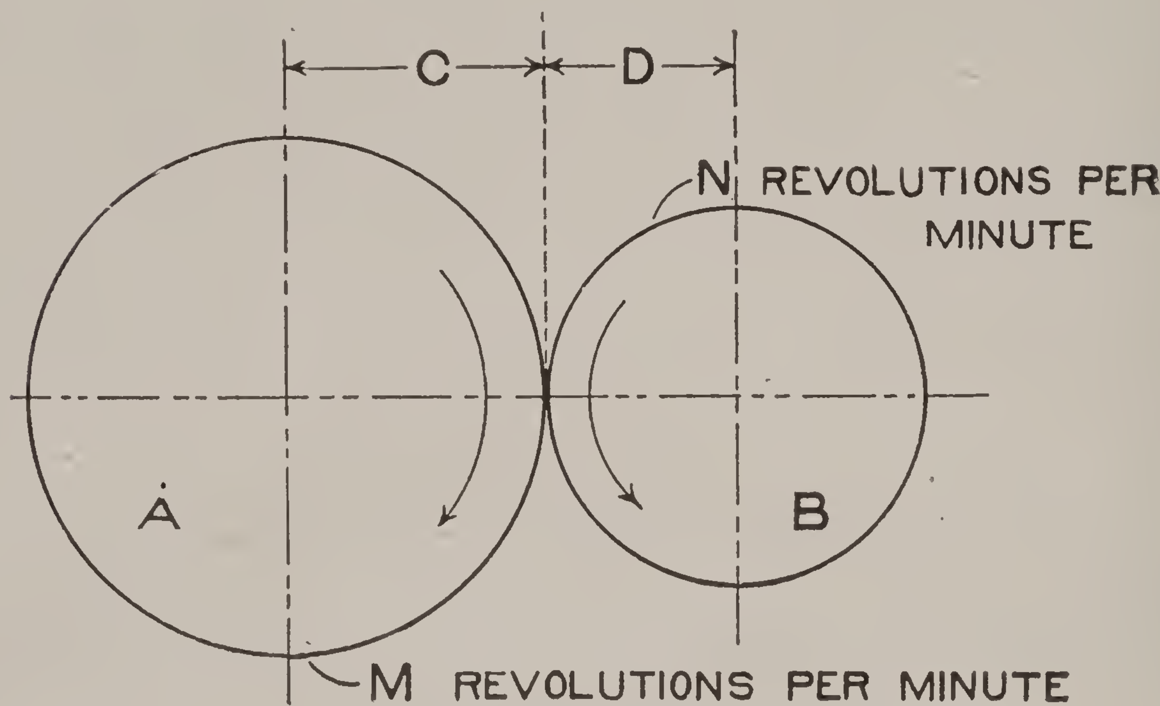


Fig. 9.

This may be stated as follows:—

$$\frac{\text{Revolutions of Driver}}{\text{Revolutions of Driven}} = \frac{\text{Radius of Driven}}{\text{Radius of Driver}}.$$

That is, the numbers of revolutions are to each other inversely as the radii, and therefore as the diameters.

Two cylinders revolving in contact, without slipping, revolve in opposite directions; that is, if A revolves right-handed (like the hands of a clock), B will revolve left-handed. This is indicated by the arrows in Fig. 9.

The following examples will illustrate the method of calculation for speeds of cylinders, according to the preceeding discussion. Suppose a wheel A, 2 feet in diameter, is revolving with its surface in contact with the surface of another wheel B. A makes

25 R. P. M. Assuming that no slipping occurs between the surfaces of the two wheels, what must be the diameter of B in order that it shall make 75 R. P. M.? From the formula (3) we have

$$\frac{\text{Diameter of B}}{\text{Diameter of A}} = \frac{\text{R. P. M. of A}}{\text{R. P. M. of B}}$$

or

$$\frac{\text{Diameter of B}}{\text{2 feet}} = \frac{25}{75}$$

$$\text{Diameter of B} \times 75 = 2 \times 25$$

therefore Diameter of B $= \frac{2}{3}$ feet $= 8$ inches.

The same principles apply to cones which are revolving in contact. Let Fig. 10 represent the side view of two right cones which are in contact along the line EF, which is an element common to both. Then.

$$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{F G}}{\text{F H}} \qquad (4$$

That is, their revolutions are to each other inversely as the diameters of their bases. If the angles OEF and O′EF are known, instead of the diameters of the bases, the ratio of the number of revolutions may be found from the following trigonometric formula:

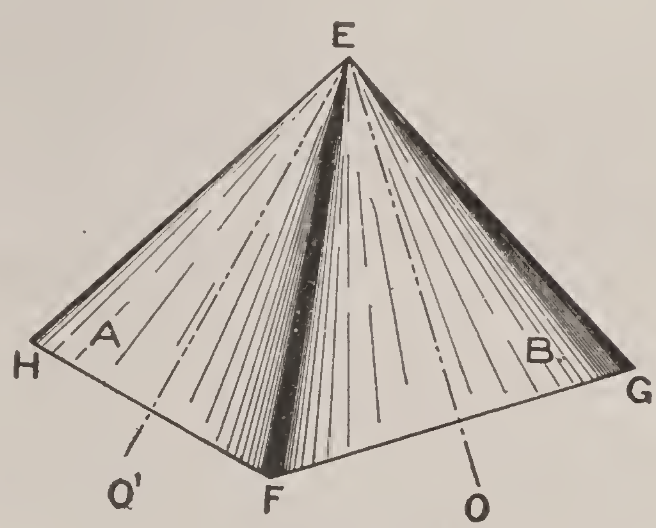


Fig. 10.

$$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{Sine of angle OEF}}{\text{Sine of angle O'EF}} \qquad (5)$$

If the angle between the axes OE and O′E is given and it is desired to find the relative sizes of the two cones whose revolutions shall have a given ratio, the angles OEF and O'EF could be calculated, but the calculation would be rather difficult and therefore a solution which is partly graphical is more convenient and usually sufficiently accurate.

Let EO′ and EO Fig. 11, be the center lines of two shafts which lie in the same plane and make an angle of 45 degrees with each other. The shafts are to be connected by two rolling

cones so that the shaft O'E shall make 30 revolutions while the shaft OE makes 40. The base of the larger cone is 12 inches, to find the base of the smaller cone and the altitude of both. Since, from the preceding discussion, the speeds are inversely as the diameters of the cones, the larger cone must be on the shaft which is making the fewer number of revolutions, that is, O'E.

Then from formula (4).

$$\frac{\text{Speed of O'E}}{\text{Speed of O E}} = \frac{\text{Diameter of base of cone on O E}}{\text{Diameter of base of cone on O'E}}$$

$$\tfrac{3}{4} = \frac{\text{Diameter of base of cone on OE}}{12}$$

Solving the equation we get

Diameter of base of cone OE = 9 inches.

Now draw the line PN parallel to O'E and at a distance from O'E equal to the radius of the base of the cone O'E (in this case 6 inches), at a convenient scale, and draw the line ML parallel to OE and at a distance equal to the radius of the base of the cone on OE (in this case $4\frac{1}{2}$ inches). These lines intersect at the point C. A line from C to E is the element along which the cones touch each other. From C draw lines perpendicular to OE and O'E, meeting them at S and R respectively. Then SE and RE are the altitudes. To draw the cones, lay off ST equal to CS, and RV equal to CR. Join E with T and V and the cones are complete.

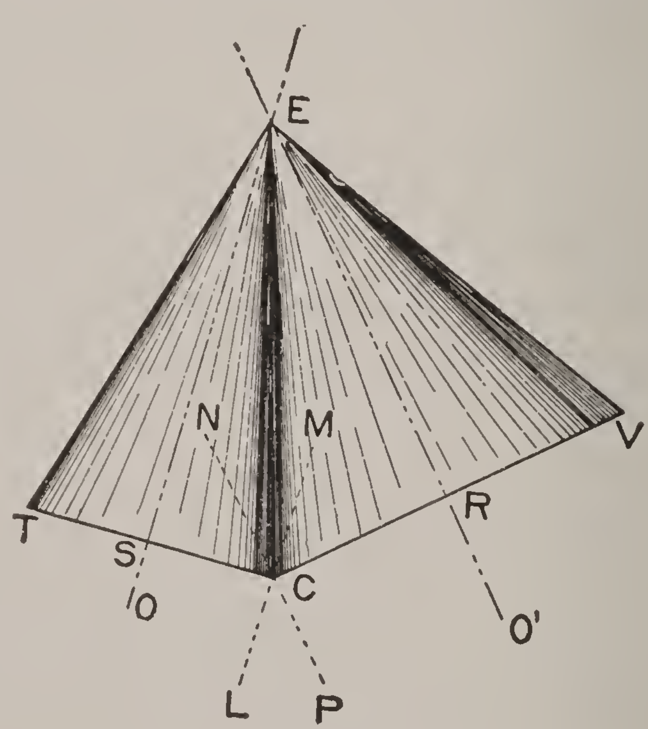


Fig. 11.

CYLINDERS AND CONES CONNECTED BY BELTS.

Frequently two shafts must be connected so that one may drive the other, and yet they are so far apart that cylinders cannot

be placed on them which will touch each other. In this case it is customary to place on each shaft a cylinder, or pulley, and over

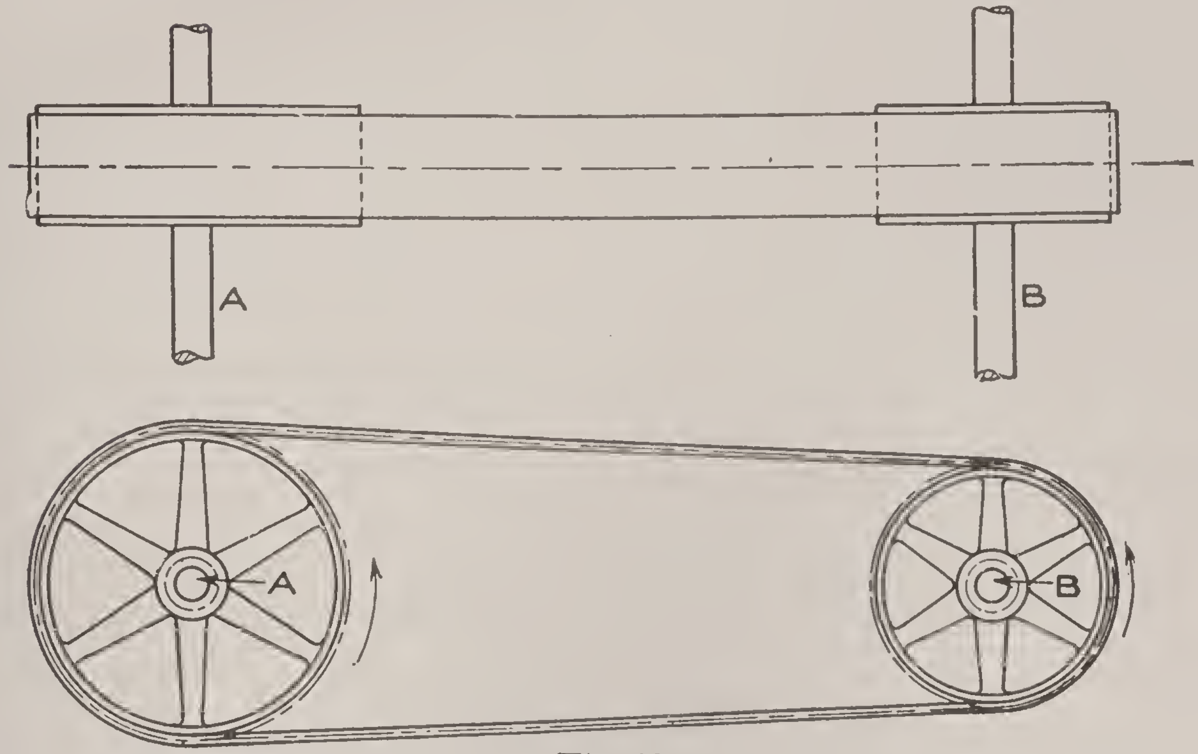


Fig 12.

these pulleys stretch a band, or belt made of some flexible material. The pulleys are fastened to the shafts so that the pulley and its shaft turn together, and the belt is stretched over the pulleys tight enough so that the friction between the belt and the surface

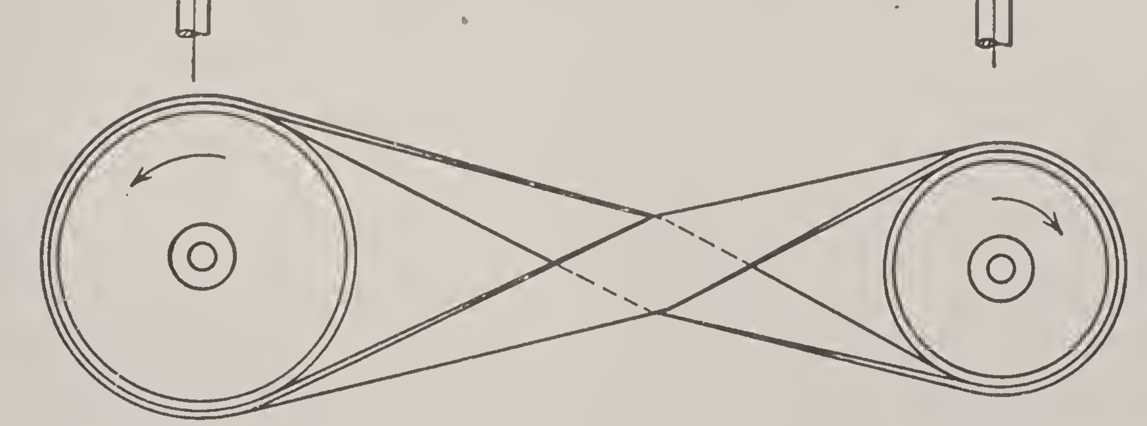


Fig. 13.

of the pulley is sufficient to make them travel with the same linear velocity. A detailed study of the exact manner of finding the proper locations of the pulleys and drawing the pulleys and belts can be found in Mechanical Drawing Part V, so that we will

now study only the general principles involved, particularly with reference to making the necessary calculations.

The principles which we learned above, concerning the relative speeds of two cylinders in contact, apply also to two pulleys connected by a belt. The rule governing the direction of rotation, however, is different. When the connection is made by means of a belt, the relation of the directions of rotation depends upon the way the belt is put around the pulleys. If the belt is put on as shown in Fig. 12, known as open belt, the pulleys will turn in the

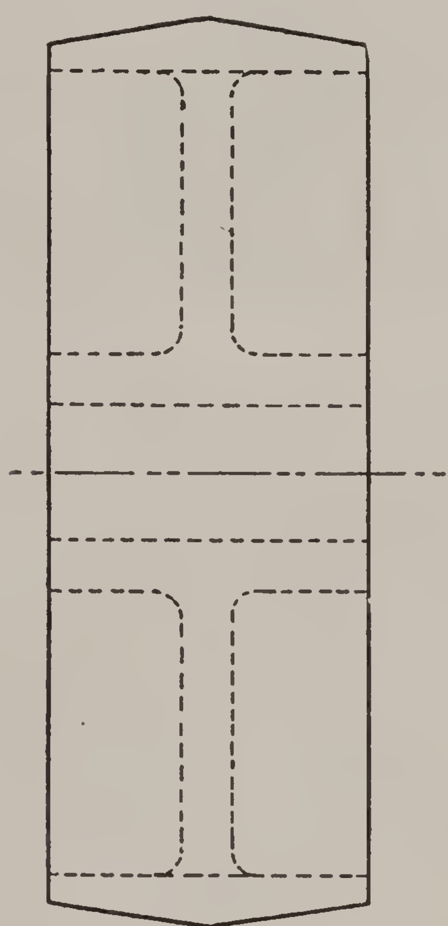


Fig. 14.

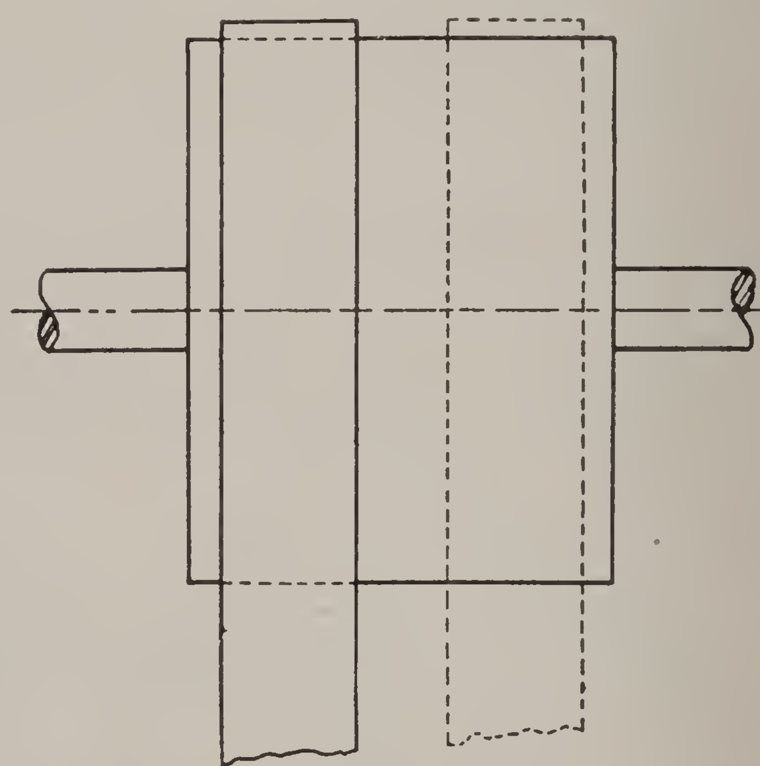


Fig. 15.

same direction. If the belt is as shown in Fig. 13, known as a crossed belt, the pulleys will turn in opposite directions.

Crowning Pulleys. The outer surface of pulleys, instead of being made cylindrical is often made of larger diameter in the middle, as shown in Fig. 14. A pulley having this increase of diameter in the middle is said to have a crowned face. The object of the crowning is to help the belt to remain on the pulley. A belt will always run to the part of the pulley which is largest in diameter; therefore, if the diameter increases towards the middle, the belt will tend to run to the middle, and will be less likely to slip off. If the belt is to be at different places on the pulley at

different times, as indicated by the full and dotted positions in Fig. 15, the surface cannot be crowned, but must be cylindrical.

As problems similar to the following often arise, this one should be studied carefully until every step is understood. In Fig. 16, A is a shaft turning 60 R. P. M. in the direction indicated by the arrow. B and C are cylinders over which a strand of cloth is to pass as indicated, the cloth passing over the top of B and under the bottom of C. In order that B and C may revolve in proper direction a crossed belt must be used between A and C,

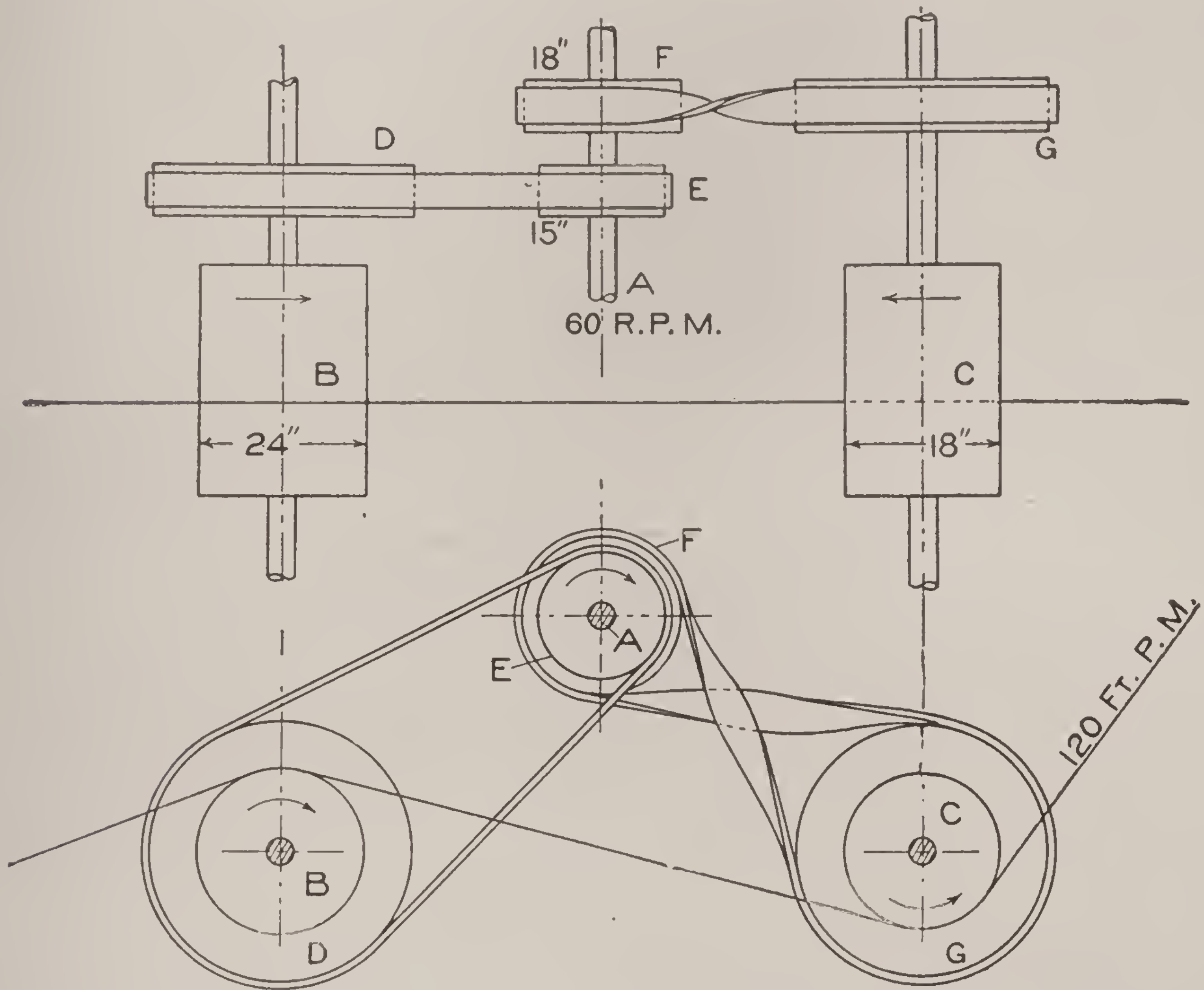


Fig. 16.

as shown. B is 24 inches in diameter, C is 18 inches in diameter, and the cloth is to travel at the rate of 120 feet per minute. E is a pulley 15 inches in diameter, which drives the pulley D, on the same shaft as B. F is a pulley 18 inches in diameter, driving pulley, G, on the same shaft as C. The problem is to find the number of revolutions of B and C, and the diameters of D and G.

The circumference of $B = 24$ inches $\times \pi = 2$ feet $\times \pi = 6.2832$ feet. Therefore, its surface velocity if it made one R. P. M. would be 6.2832 feet per minute. But since it is to have a surface

velocity $= 120$ feet per minute (equal to that of the cloth) its speed must be 120 divided by $6.2832 = 19.1$ R. P. M. Revolutions of C are found in the same way.

18 inches $= 1.5$ feet. 1.5 feet $\times 3.1416 = 4.7124$ feet $=$ surface speed.

120 divided by $4.7124 = 25.4$ R. P. M.

Now from formula (3):

$$\frac{\text{Revs. of D}}{\text{Revs. of E}} = \frac{\text{Diameter of E}}{\text{Diameter of D}}$$

and since the revolutions of D $=$ the revolutions of B

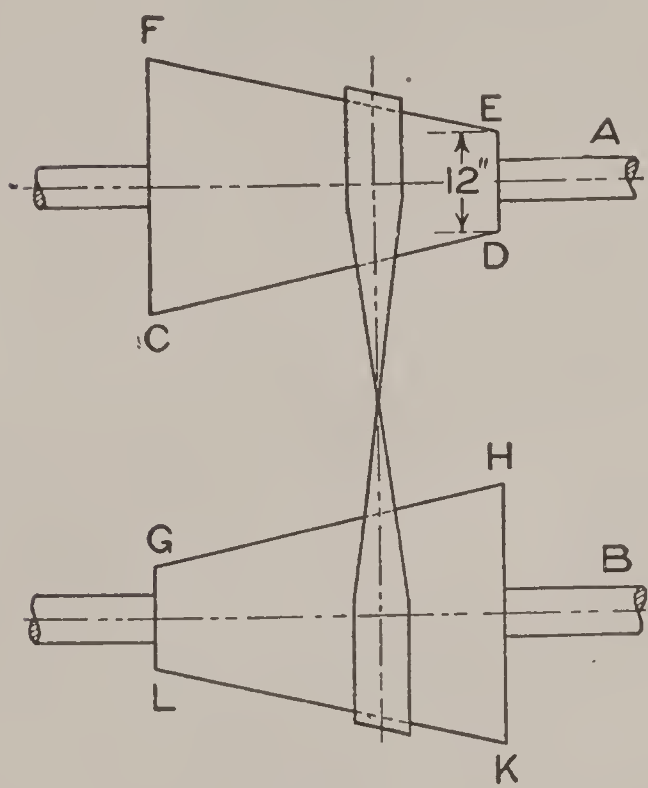


Fig. 17.

$$\frac{19.1}{60} = \frac{15}{x}$$

$$19.1\,x = 15 \times 60$$

$$x = 47.12 +$$

therefore, pulley D is $47\frac{1}{8}$ inches in diameter.

$$\frac{\text{Revs. of G}}{\text{Revs. of F}} = \frac{\text{Diameter of F}}{\text{Diameter of G}}$$

$$\frac{25.4}{60} = \frac{18}{x}$$

$$25.4\,x = 18 \times 60$$

$$x = 42.5 \text{ (approx.)}$$

therefore, pulley G is 42.5 inches in diameter.

Taper Cones. Suppose two equal frustums of cones are arranged on parallel shafts, as shown in Fig. 17. Shaft A, turning at a constant speed, can be made to drive shaft B at different speeds by changing the location of the belt on the cones. In order to use cones with a straight taper, a crossed belt should be used. If an open belt is used, the cones should be shaped as shown in Fig. 18. It is necessary to give this curvature to the face in order to keep the same tension on the belt for different positions. With a crossed belt this condition is fulfilled by making the face a straight line. If the shafts are far apart, the straight cones are sometimes used for an open belt.

Since the calculations for finding the proper shape of the cones for an open belt are difficult and are not often needed, we will give our attention only to the straight cones for a crossed belt.

In Fig. 17 let shaft A be the driver, turning at a constant speed of 100 R. P. M. The small end of the cone on A is 12 inches in diameter. We wish to find the diameter of the large end of the cone on B, in order that the slowest speed of B may be 75 R. P. M. Then, if the cones are alike, to find the greatest speed of B:

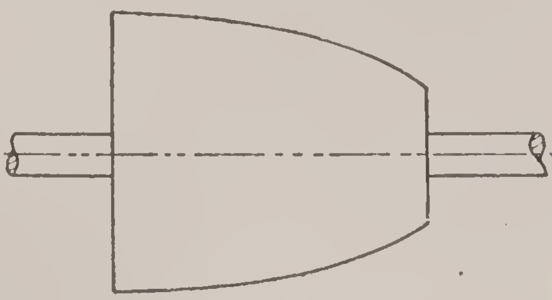


Fig. 18.

First $$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{H K}}{\text{E D}}$$

$$\frac{100}{75} = \frac{\text{H K}}{12}$$

$$75 \text{ H K} = 12 \times 100$$

Therefore $\text{H K} = \frac{1200}{75} = 16$ inches.

Now, if the cones are equal

and $$\text{G L} = \text{E D} = 12$$
$$\text{F C} = \text{H K} = 16.$$

Then $$\frac{\text{R. P. M. of A}}{\text{R. P. M. of B}} = \frac{\text{G L}}{\text{F C}}$$

$$\frac{100}{x} = \frac{12}{16}$$

$$x = \frac{1600}{12} = 133\tfrac{1}{3}.$$

Therefore, the larger ends of the cones must be 16 inches in diameter and B will have a variation of speed from 75 R. P. M. to $133\frac{1}{3}$ R. P. M The length of the cone does not affect the extreme speeds, but the longer the cones the more easily the intermediate speeds may be obtained.

Cones arranged as explained above are used to drive drying machines in bleacheries and similar places, where it is desired to vary the speed af the machine according to the weight of the cloth which is being dried. Heavy cloth requires a longer time to dry than light cloth and consequently can not be passed through the

machine as rapidly. Tapered cones are also found in various cotton machines.

Stepped Cones. Stepped cones are often used in place of the tapered cones. These are really a series of pulleys side by side on a shaft, a similar series being placed on the other shaft with the large pulley on the second shaft in line with the small pulley on the first shaft. The arrangement is shown in Fig. 19. In practice the several pulleys which make up the stepped cones are cast together, both cones usually being cast from one pattern. The cal-

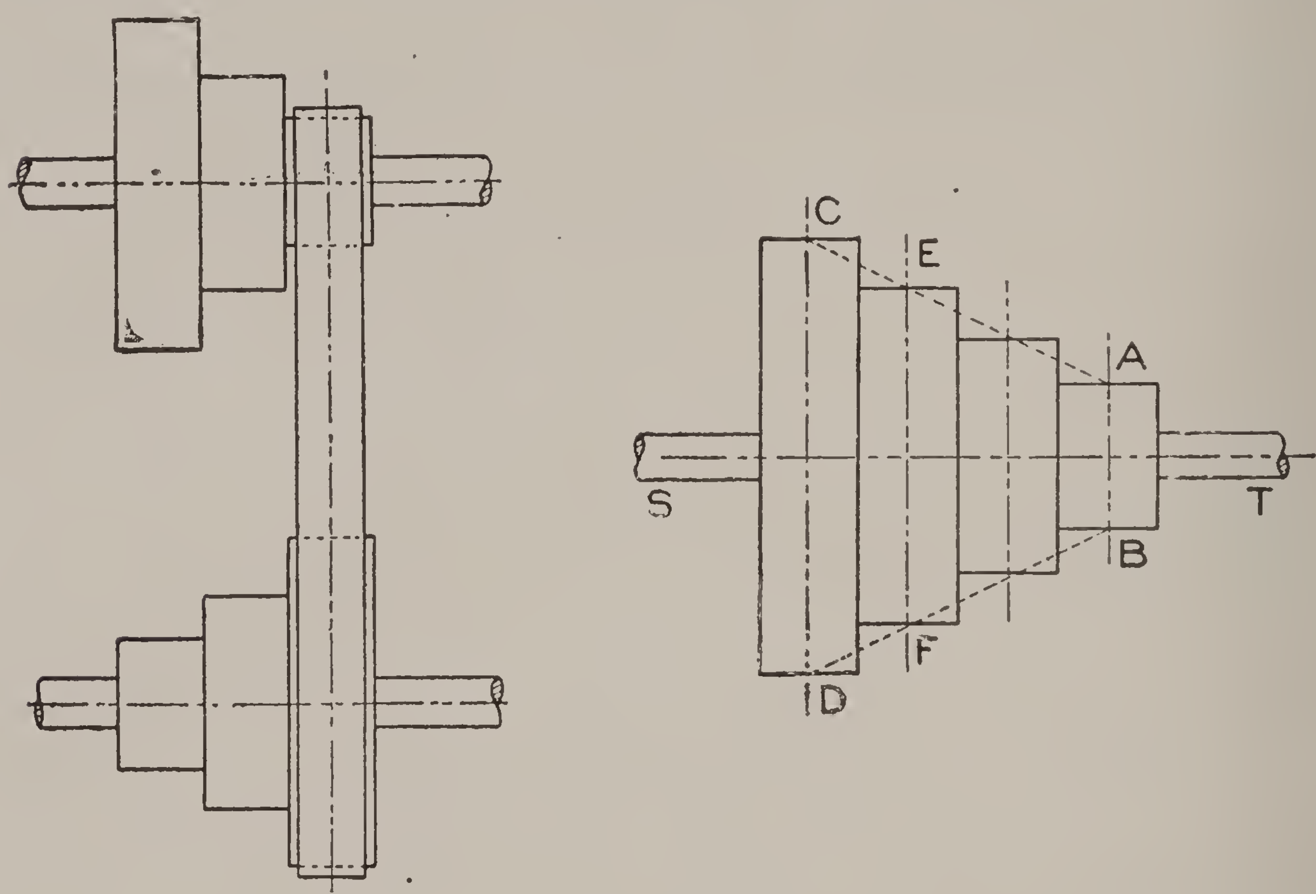


Fig. 19.

culation for the diameters of the end steps are the same as for the end diameters for the cones (Fig. 17). Assuming that both cones are alike, the intermediate steps can be found as follows:—

Decide how many intermediate steps are desired, then draw the center line ST, and draw the lines AB and CD perpendicular to ST and at a distance apart equal to the width of the face of one step multiplied by the whole number of steps minus one. Make CD equal in length to the diameter of the largest step and AB equal to the diameter of the smallest step. Draw AC and BD. Draw EF parallel to and at a distance from CD equal to the width of the face of one step. The distance between E and F, the points where EF intersects AC and BD, will be the diameter of the sec-

ond step. Other steps may be found in the same manner. To use this method all steps must have the same width of face. It would not be accurate for an open belt, although if the distance between the shafts are large compared with the diameter of the cones, an open belt might not give trouble on cones designed in this way.

Stepped cones are very commonly used for driving lathes and other machine tools.

EXAMPLES FOR PRACTICE.

1. A shaft making 115 revolutions per minute has keyed to it a pulley 36 inches in diameter. If the pulley belted to the 36-inch pulley is 26 inches in diameter, how many revolutions will it make per minute?

Ans. 160 revolutions. (nearly.)

2. A pulley 12 inches in diameter makes 180 revolutions per minute. The other pulley connected by belt to the 12-inch pulley should make 75 revolutions. How large must it be?

Ans. 28.8 inches in diameter.

3. A motor shaft having a pulley 6 inches in diameter makes 840 revolutions. If this speed is to be reduced to 320 revolutions, what size pulley should be used?

Ans. $15\frac{3}{4}$ inches in diameter.

Disk and Roller. Fig. 20 shows a device by means of which one shaft turning always in the same direction with a constant speed may drive another shaft, which is at right angles to it, in either direction and at different speeds. A is a disk on the end of the overhanging shaft S. On the shaft T is placed a roller B free to be moved up or down on T, but on a key so that it must turn with the shaft. Some sort of a shipper must be provided to hold B in the desired position on T. When one shaft turns it drives the other by means of the friction between A and B. If shaft S is the driver, turning in the direction indicated by the arrow, it will cause T to turn in the direction indicated by the lower arrow. If it is desired to have T turn in the opposite direction, keeping the direction of S the same, B must be moved up above the center line of S as shown dotted. If OR is the distance from the center of disk A to the point where the center line of the face of B strikes

A, and LR is the radius of B, we have the following equation,—

$$\frac{\text{R. P. M. of B}}{\text{R. P. M. of A}} = \frac{\text{O R}}{\text{L R}} \qquad (6)$$

from which, knowing the speed of one, the speed of the other may be calculated. It will be seen from this equation that if OR is decreased, that is, if B is moved nearer the center line of S, the speed of B will decrease if A is the driver, or the speed of A will increase if B is the driver.

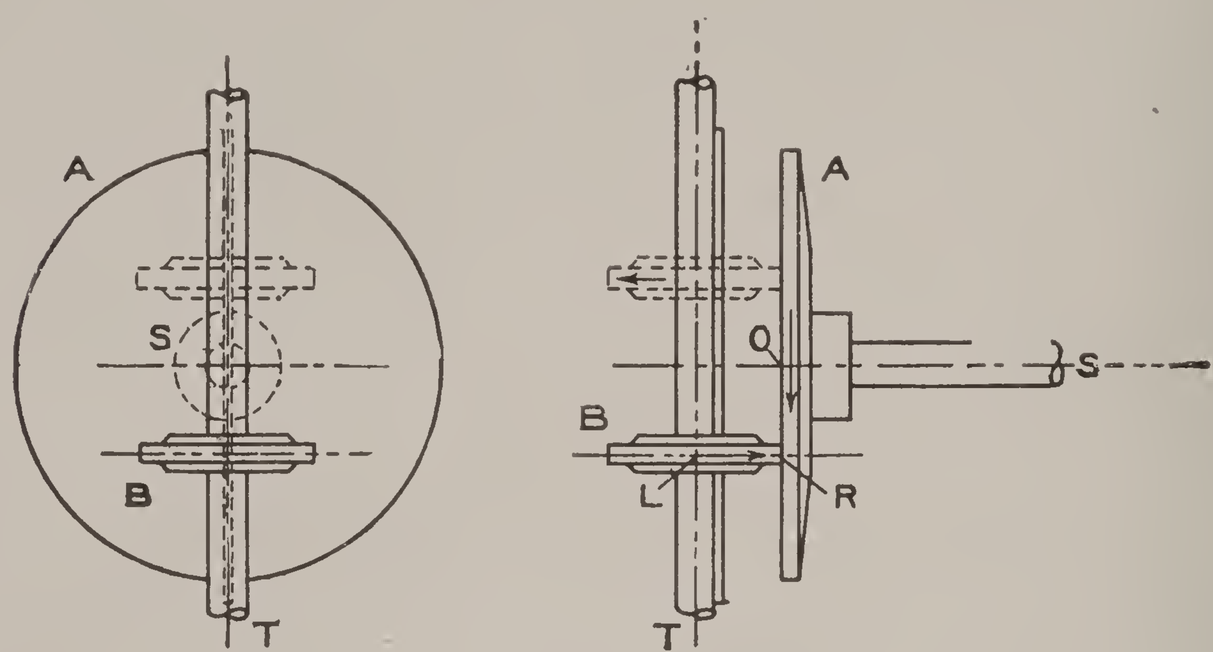


Fig. 20.

This device is used for driving drying machines where the cloth goes from another machine direct to the drying machine, and it is essential that the speed of the two should be adjusted to a nicety, in order that excessive strain may not come upon the cloth. It is also used for driving the feed mechanism on machine tools, particularly drills.

Example: Suppose the disk A makes 70 revolutions per minute and disk B 124 revolutions. If OR is 18 inches what is the diameter of B?

$$\frac{\text{R. P. M. of B}}{\text{R. P. M. of A}} = \frac{\text{O R}}{\text{L R}} \text{ or } \frac{124}{70} = \frac{18}{\text{L R}}$$

$$124 \times \text{L R} = 70 \times 18$$

$$\text{L R} = \frac{70 \times 18}{124}$$

$$= 10.16 \text{ inches (about).}$$

Diameter would be $2 \times 10.16 = 20.32$ inches or $20\frac{5}{16}$ inches.

EXAMPLE FOR PRACTICE.

1. Disc B, Fig. 20, is 12 inches in diameter and makes 280 revolutions per minute. If shaft S is to make 48 revolutions per minute how far from the center must the circumference of B be placed? Ans. 35 inches.

DISCONNECTING AND REVERSING MECHANISMS.

Tight and Loose Pulleys. Fig. 21 shows a very common arrangement of pulleys, whereby the shaft A may be stopped while the driving shaft B continues to run. Pulley C is keyed to

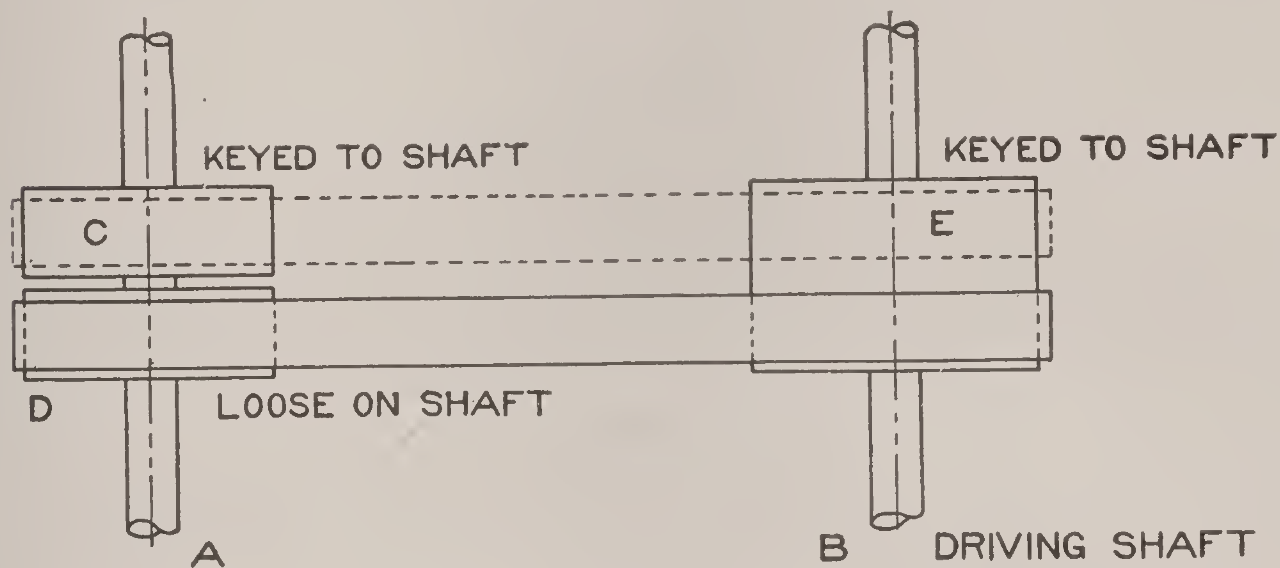


Fig. 21.

shaft A, while pulley D is free to run on A. Pulley E has its face equal in width to the sum of the other two and is keyed to B. When the belt is in the position shown in full lines, D turns with E, while shaft A remains at rest. The belt is guided by a shipper and when it is desired to start A, the belt is moved into the position shown by the dotted lines.

Jaw Clutch. Fig. 22 illustrates an arrangement by which the gear, or pulley, A may be attached to turn with the shaft, or disconnected so as to turn independently of the shaft. The hub of A has jaws or teeth on its end, and the sliding piece B has similar teeth, the projections on B fitting into the indentations of A. The shaft may turn freely in A while B slides on a key so that it must turn with the shaft. When B is in the position shown, the shaft and A may turn independently of each other, but when B is

moved to the left so that its teeth engage with the teeth on the hub of A, it serves to clamp A to the shaft. The principle here involved is used in many different forms of clutches.

Friction Clutches. A jaw clutch such as illustrated in Fig. 22, if thrown in while the shaft or gear is turning brings a sudden shock on the parts, which is likely to cause damage, especially if the speed is high and much power is transmitted. Consequently, a clutch known as a friction clutch is often used, which, as its action depends upon the friction between two parts, will impart motion more gradually thereby avoiding the shock. Fig. 23 illus-

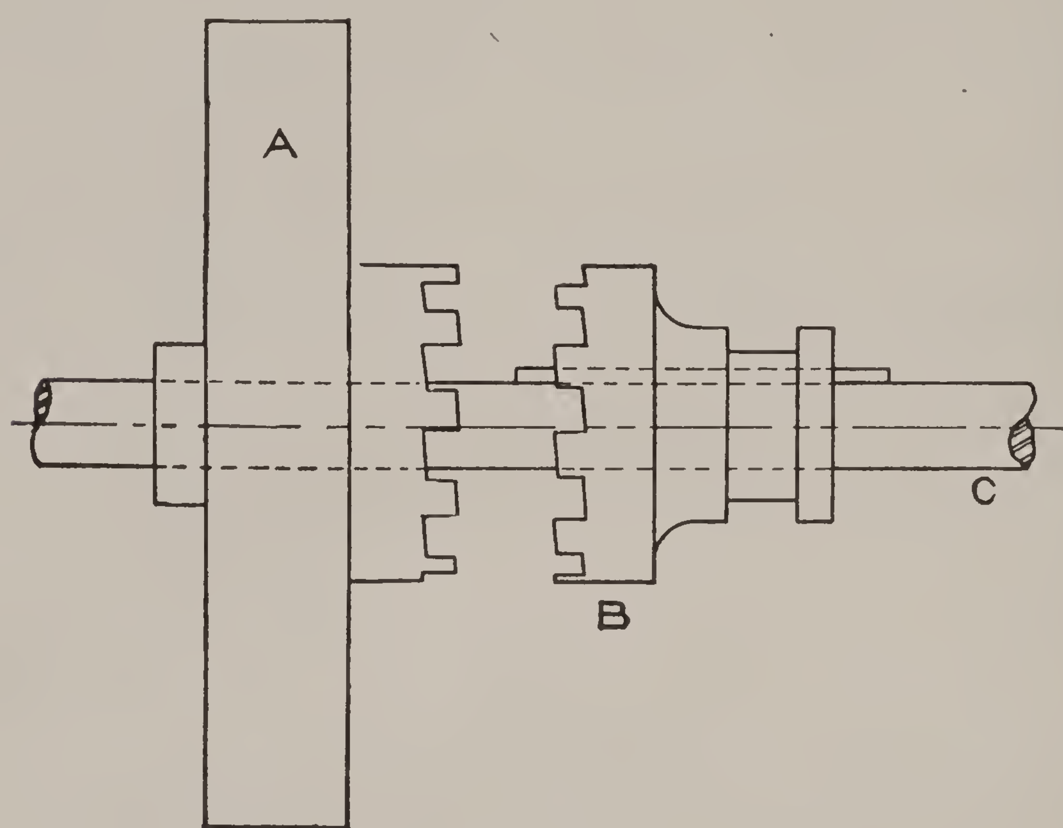


Fig. 22.

trates a simple clutch of this kind. B is a piece free to slide on a key, and held in position by a shipper. A is a pulley or gear loose on the shaft. The outer surface of B and the inner surface of A are tapered to fit each other. When B is thrown to the left it clamps A to the shaft in the same manner as the jaw clutch.

Two Clutches for Reversing. Fig. 24 shows how two clutches can be arranged so that either one may be thrown in, thus giving motion to the shaft in either direction. The clutches are similar in principle to the one shown in Fig. 23. The left-hand clutch is shown partly cross-sectioned. The piece A is attached to a shipper which when moved to the right throws in the right-hand clutch; when moved to the left throws in the left-hand clutch. If the pul-

ley of the right-hand clutch is driven by an open belt and the pulley of the left-hand clutch by a crossed belt, the shaft will be driven

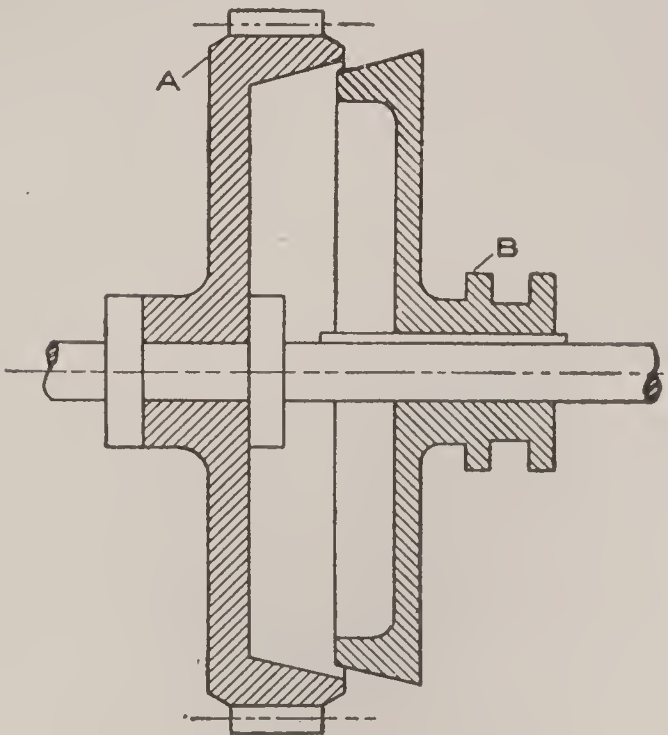


Fig. 23.

in either direction according as one or the other clutch is thrown in. When A is in the position shown neither clutch is in and the shaft is at rest.

SCREWS.

The Helix. Since all screws depend upon a curve known as

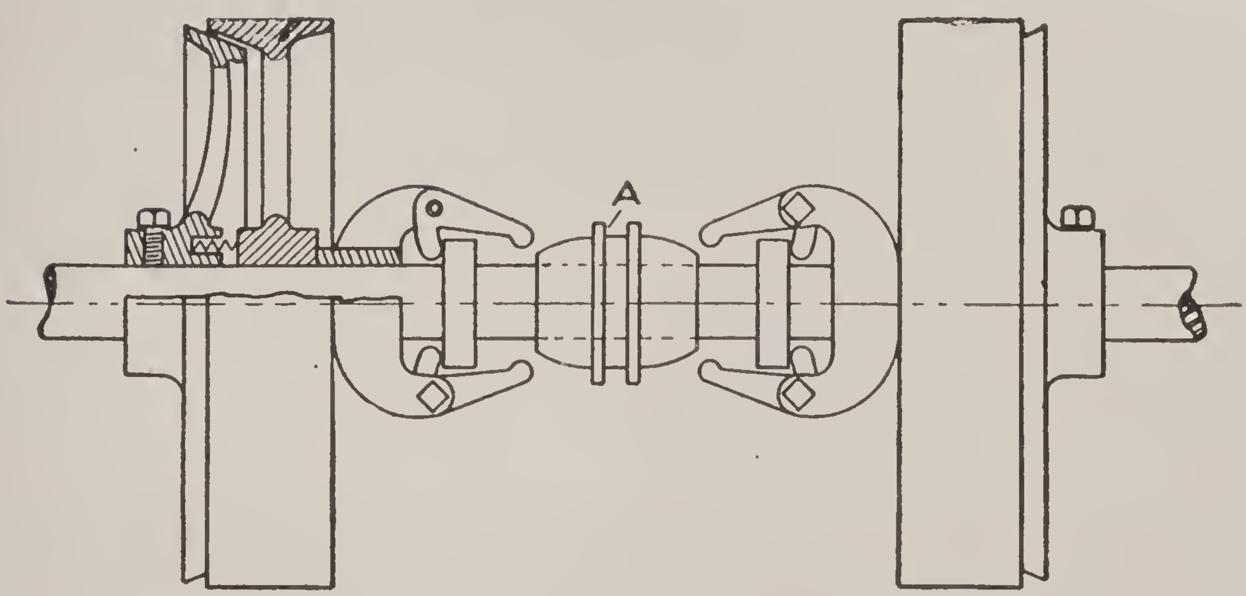


Fig. 24.

the helix, it will be necessary to understand something about this curve before attempting the study of the screw.

Take a cylindrical piece of wood, such as is shown in Fig. 25, and a rectangular piece of paper, ABFE, with the side AB equal

to the circumference of the cylinder, and the side AE equal to the length of the cylinder. Now, if we lay off along AE a distance

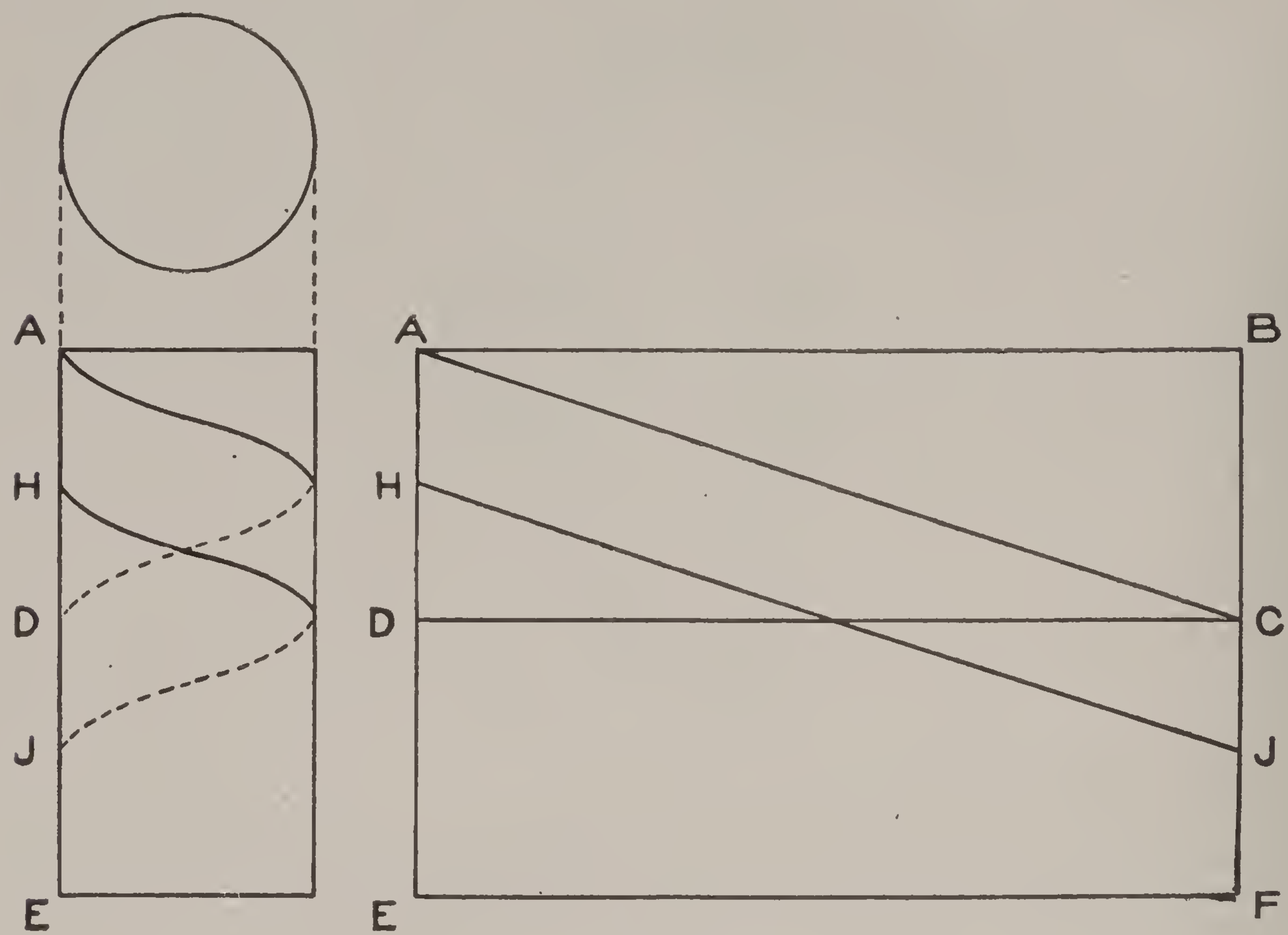


Fig. 25.

AD, and draw the line DC parallel to AB, we have the rectangle, ABCD. Now draw the diagonal, AC, of the rectangle and wrap the paper around the cylinder, keeping the side AE on an element of the cylinder; the paper will just cover the cylinder, the edge

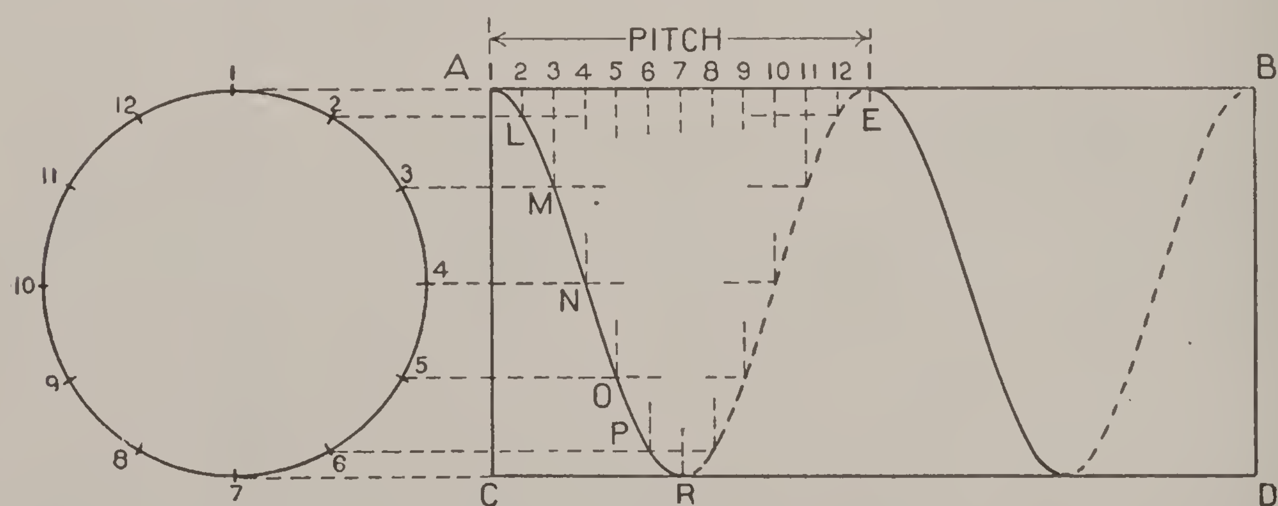


Fig. 26.

BF meeting the edge AE. The point C will coincide with D and lie on the same element of the cylinder as A and at a distance from A equal to AD. The shape which the line AC now takes is called a helix, and the distance AD is called the pitch of the helix. If

we choose another point, H, half-way between A and D, and draw a line HJ parallel to AC, this line when wrapped around the cylinder will form another helix of the same pitch as the first one. The two together form what may be called a double helix. If the line AD is divided into three equal parts instead of two, and lines

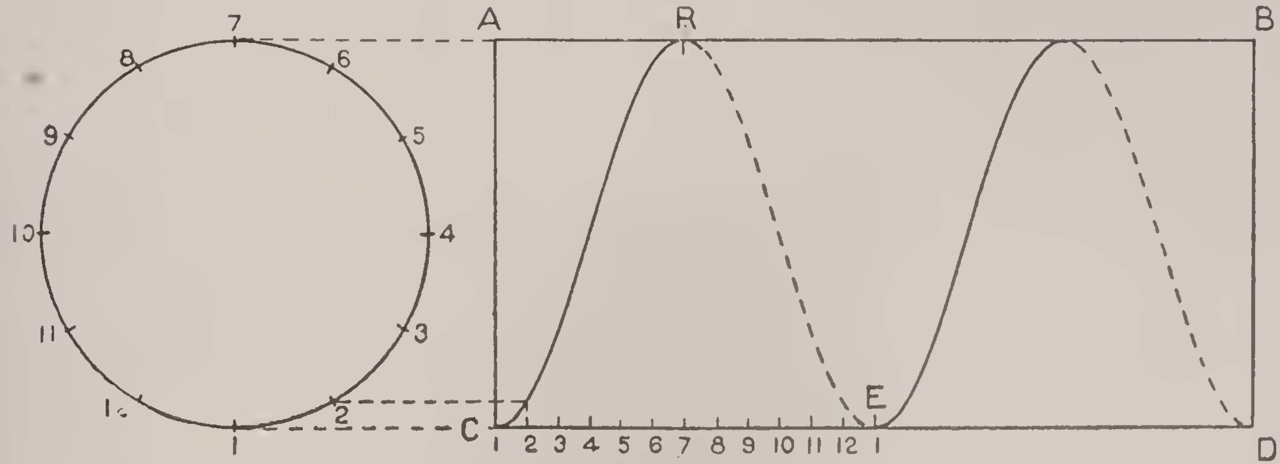


Fig. 27.

parallel to AC be drawn from each of the points of division, we would have on the cylinder three parallel and equidistant helices of the same pitch, or a triple helix. Fig. 26 shows a single right-hand helix, Fig. 27 a single left-hand helix, Fig. 28 a double right-hand helix, and Fig. 29 a triple right-hand helix.

If a helical groove is cut on the surface of a cylinder, a screw

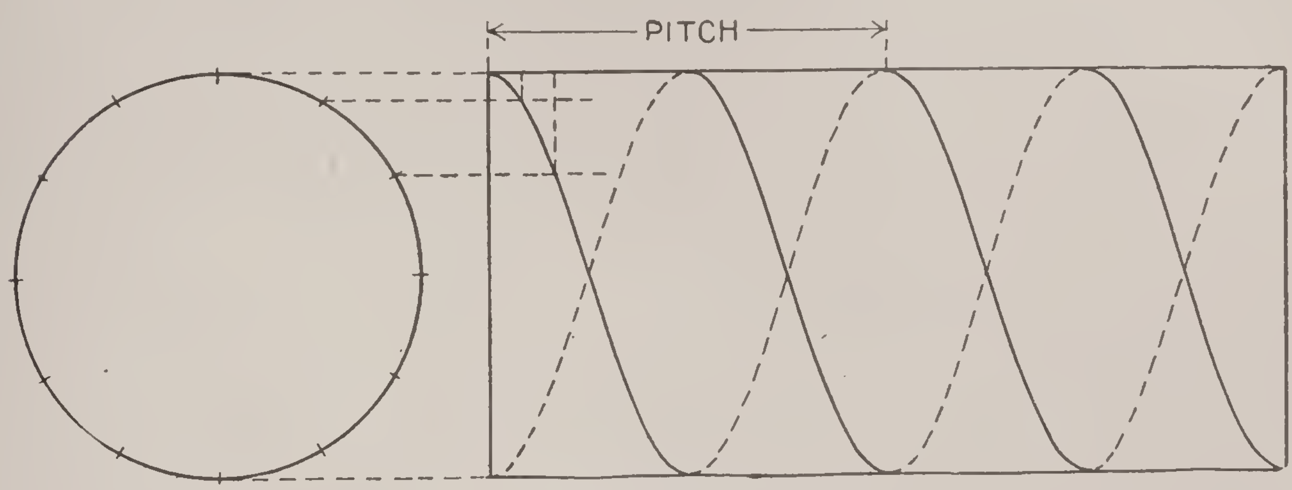


Fig. 28.

thread is formed, the thread being the material which is left between the successive turns of the helical groove. A cylinder having a thread on it is called a screw, and a piece having a cylindrical hole in it, with a thread around the hole, is called a nut. The groove which is cut to form the thread may be in the form of a single, double or triple helix, and either right-hand or left-hand; the thread would be described in the same terms.

Fig. 30 shows a right-hand and a left-hand single V thread and a right-hand and a left-hand single square thread.

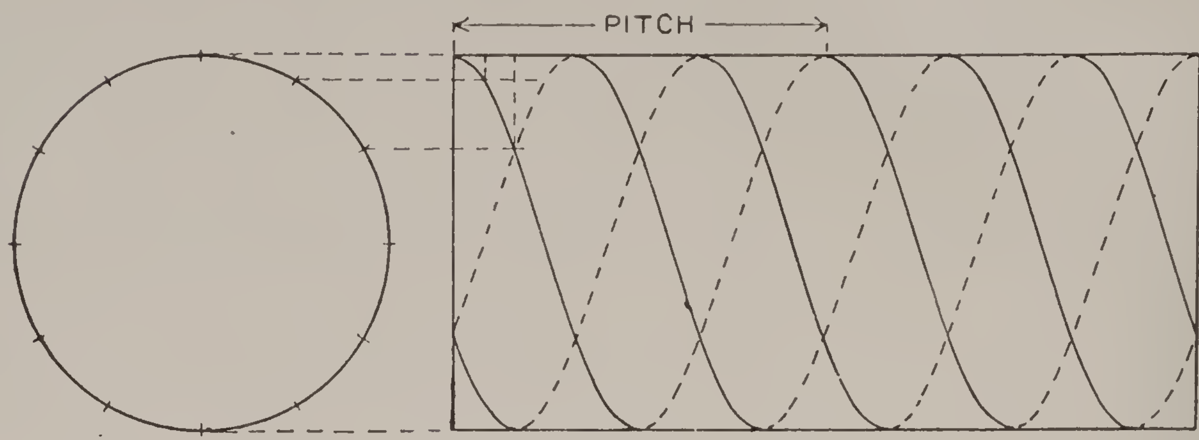
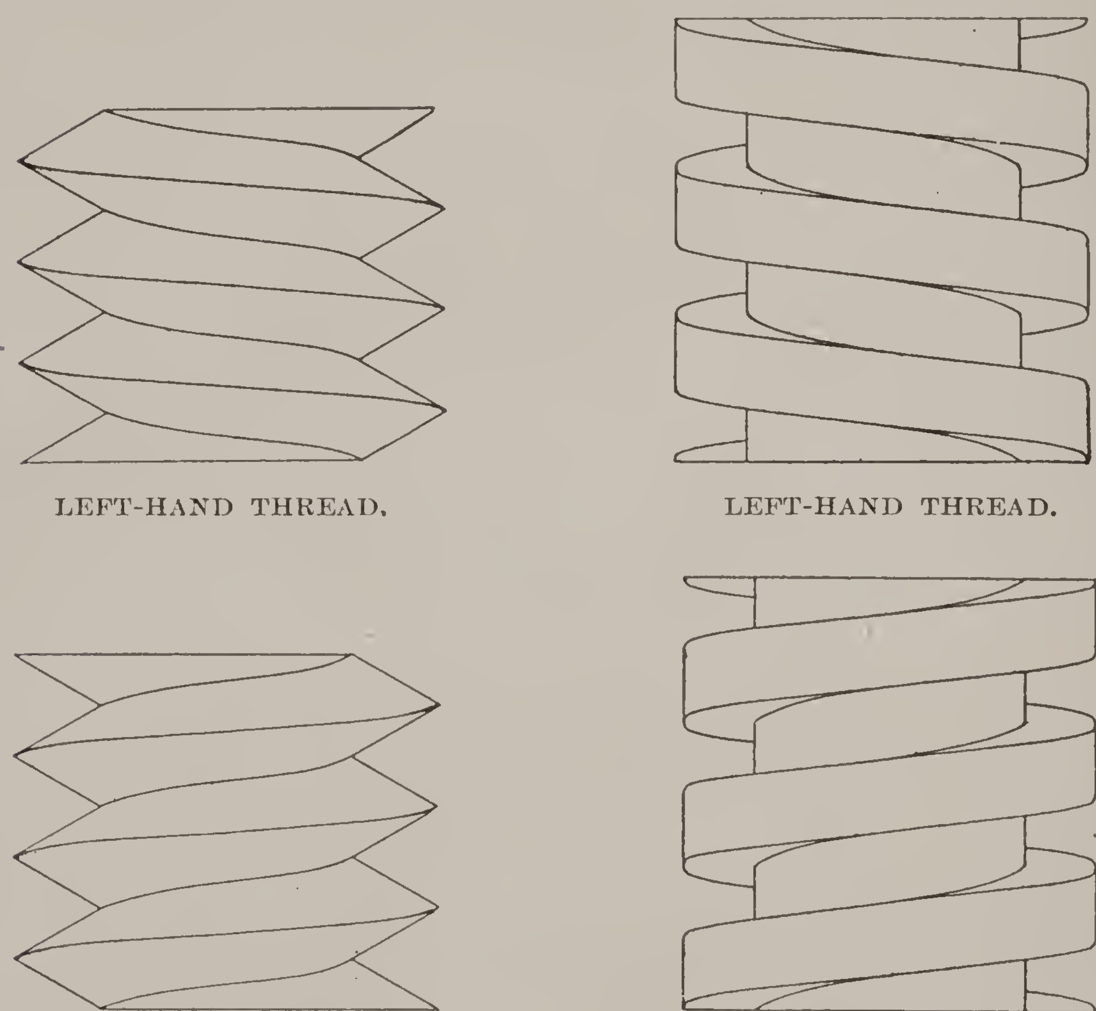


Fig. 29.

One complete turn of a screw causes it to travel through its nut a distance equal to its pitch.



LEFT-HAND THREAD. LEFT-HAND THREAD.

RIGHT-HAND THREAD. RIGHT-HAND THREAD.

Fig. 30.

There are certain principles which apply and certain problems which arise, in connection with all forms of screws, and we shall now consider some of the most important of these.

Let Fig. 31 represent a jack screw. The pitch of the screw is P inches; the length of the bar from the axis of the screw to

the point R, where the force is applied, is A inches. A force of F pounds is exerted at R, raising the weight W.

The following equation holds true,

$$\frac{F}{W} = \frac{\text{Distance W moves}}{\text{Distance F moves}} \qquad (7)$$

Suppose the screw to be turned once; then F will move through a distance approximately equal to the circumference of a circle whose radius is A; that is, F moves a distance $2\pi A$. In turning the screw once, W is raised a distance P. Then, substituting, in equation (7), these quantities for the distances which F and W respectively move, we get

$$(8) \quad \frac{F}{W} = \frac{P}{2\pi A} \quad \text{or}$$

$$2\pi A F = W \times P$$

$$W \times P = 2\pi A \times F$$

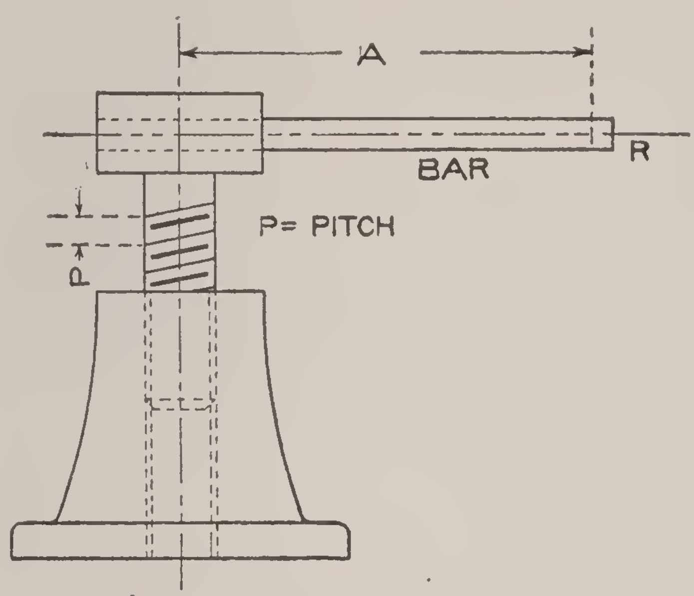


Fig. 31.

From this equation, if any three of the quantities F, W, P or A are known, the fourth may be found. P and A must both be expressed in feet or both in inches.

For example, let $P = \frac{1}{4}$ inch, $A = 5$ feet, $F = 100$ pounds. Substituting in the formule we get

$$\frac{100}{W} = \frac{.25}{2 \times 3.1416 \times 60}$$

$$.25\,W = 37699.2$$

$$W = 150{,}797 \text{ pounds (nearly).}$$

EXAMPLES FOR PRACTICE.

1. Suppose a weight of 200,000 pounds is to be raised by a jack screw. The pitch is .20 inch, and the force applied is 125 pounds. What must be the length of the bar?

Ans. 51 inches (nearly).

2. What should be the pitch of the screw of example 1 if the bar is made 6 feet long? Ans. .28+ inches.

3. A jack screw has the following dimensions: Length of arm, $5\frac{1}{2}$ feet; pitch, .125 inch. If 200,000 pounds are to be raised what force must be applied at the end of the bar?

Ans. 60 pounds.

Combination of Screws. Fig. 32 illustrates a method by which the space moved through by the nut C may be made very small in comparison with the space moved through by a point on the circumference of the hand wheel, without using a very fine pitch on the screw. Great pressure can thus be produced at C by a small force on the wheel, without danger of stripping the thread, which might occur if the screw had a fine pitch. The upper part of the screw E has a coarse thread which acts in the nut B, this nut being rigid with the frame D. The lower part of the screw has a pitch different from the upper part and acts in the nut C. C is free to slide up or down in the frame, but is prevented from turning by the lips L.

Let P = the pitch of the upper part of the screw and p = the pitch of the lower part, both threads being right-hand, and P being greater than p. If the screw were attached to C by a collar instead of being threaded into it, one turn of the screw right-handed in nut B would cause the screw to advance a distance P, carrying C forward the same distance. But since by the same turn the screw has drawn nut C on to itself a distance p, the actual distance, K, which C has advanced is

$$K = P - p \tag{9}$$

If p were greater than P, K would have a minus value; that is, C would actually move up for a right-handed turn of the screw. If one of the screws is left-handed and the other right-handed, the equation would become

$$K = P + p. \tag{10}$$

Let $P = \frac{1}{4}$ inch and $p = \frac{3}{16}$ inch, and let both screws be right-handed. If the radius A of the hand wheel is 12 inches, how much pressure can be exerted at C by a force of 50 pounds, applied to the circumference of the wheel?

The same principle holds here as in the case of a simple screw; that is, the forces exerted are inversely as the distances moved through, or,

$$\frac{\text{Force at wheel}}{\text{Force at C}} = \frac{\text{Travel of C}}{\text{Travel of point on circum. of wheel}} \qquad (11)$$

so that we must first find the distance C moves for one turn of the wheel. Substituting the values of P and p in formula (9), we get

$K = \frac{1}{4} - \frac{3}{16} = \frac{1}{16} =$ distance C moves for one turn of the screw.

The distance which a point on circumference of wheel moves

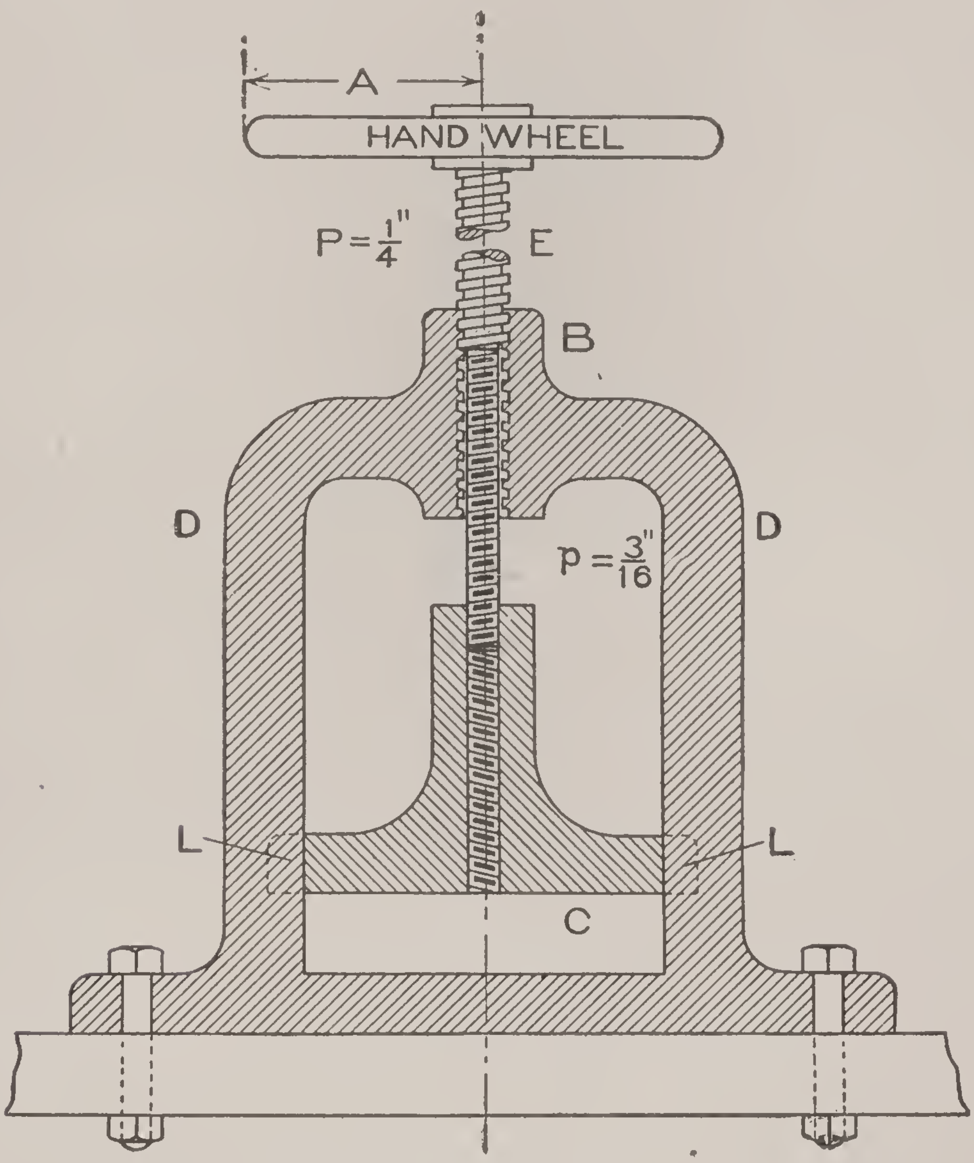


Fig. 32.

$= 2\pi A = 2 \times 3.1416 \times 12 = 75.4$ inches. Substituting these values in formula (11) we get

$$\frac{50}{\text{Force at C}} = \frac{\frac{1}{16}}{75.4}$$

Solving, we get, force at C = 60,320 pounds.

EXAMPLE FOR PRACTICE.

1. Suppose the press shown in Fig. 32 has the following dimensions: $P = \frac{1}{5}$ inch, $p = \frac{1}{6}$ inch, and the force at C is to be 78,000 pounds. What force must be applied to the circumference of the wheel if it is 14 inches in diameter?

Ans. 60 pounds (nearly).

Worm and Wheel. The mechanism known as worm and wheel consists of a wheel, as A, Fig. 33, having teeth on its circumference, and a screw or worm W, meshing with the teeth on the wheel. The axis on which the wheel is fixed is usually at right angles to the axis of the worm. If the worm is turned, the action between it and the teeth on the wheel is similar to the action between a screw and the thread in a nut, so that the wheel will turn also. If the worm is single-threaded, one turn of the worm will cause the wheel to advance one tooth, so that in order for the wheel to make one complete revolution, as many turns of the worm will be required as there are teeth in the wheel. If the worm is double-threaded, half as many turns will be required as there are teeth in the wheel; if the worm is triple-threaded, one-third as many turns will be required as there are teeth in the wheel.

Suppose the worm be single-threaded and turned by a crank whose length is R; let the worm wheel have n teeth and have on its shaft a cylinder of radius K, with a cord wound around it supporting the weight L. If a force of F pounds is applied to the crank, the same principle holds true as in the other mechanisms which we have studied, namely,

$$\frac{F}{L} = \frac{\text{Distance L moves}}{\text{Distance F moves}} \qquad (12)$$

If the worm makes one revolution, F will move through a distance $2\pi R$. The wheel makes $\frac{1}{n}$ revolutions, and consequently the cylinder to which L is attached will make $\frac{1}{n}$ revolutions. If the cylinder made a whole revolution it would raise L a distance equal to its circumference $= 2\pi K$, therefore, when it makes one revolution it will raise L a distance $\frac{2\pi K}{n}$ Substituting this value for the distance L moves, in formula (12), and substituting for distance F moves, the quantity $2\pi R$, we get

$$\frac{F}{L} = \frac{\frac{2\pi K}{n}}{2\pi R} = \frac{2\pi K}{2\pi nR}$$

Therefore,

$$\frac{F}{L} = \frac{K}{nR} \tag{13}$$

If the worm is double-threaded, L will be raised twice as far for one turn of the worm, so that the above formula would become for a double threaded worm and wheel,

$$\frac{F}{L} = \frac{2K}{nR} \tag{14}$$

and for a triple-threaded worm and wheel,

$$\frac{F}{L} = \frac{3K}{nR} \tag{15}$$

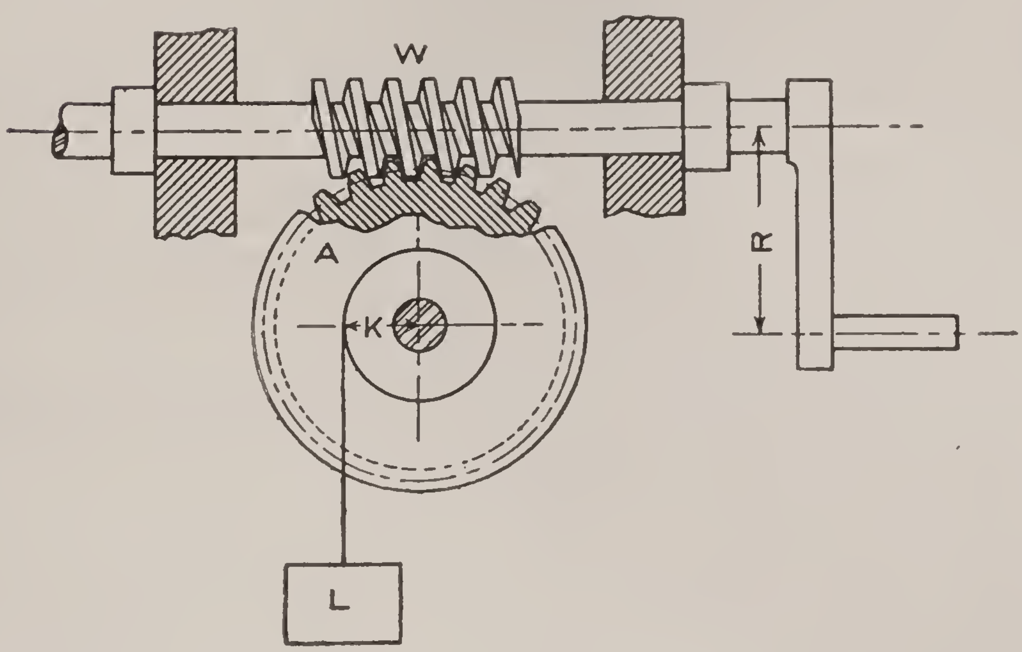


Fig. 33.

For example, a single-threaded worm makes 180 revolutions per minute and the worm wheel has 30 teeth, how many feet per minute will a weight be raised if the cylinder on the shaft of the worm wheel is 12 inches in diameter?

For each revolution of the worm wheel the worm must make 30 revolutions, hence the worm wheel makes 6 revolutions per minute. The circumference of the cylinder is $2\pi R$ or $2 \times 3.1416 \times 6 = 37.699$ inches and $6 \times 37.699 = 226.197$ inches $= 18.85$ feet.

EXAMPLES FOR PRACTICE.

1. A crank of 18 inches radius is attached to a worm of a single thread. The worm wheel has 48 teeth and is attached to a drum 14 inches in diameter. What weight can be raised if 80 pounds is applied to the crank?

Ans. 9874 pounds.

2. If the crank in above device is given 216 revolutions per minute how fast will the weight rise?

Ans. $16\frac{1}{2}$ feet (nearly).

3. How fast would it rise if the worm has a double thread?

Answer 33 feet.

CAMS.

A cam is a plate or cylinder having a curved outline, or a curved groove in it, which, by its rotation about a fixed axis, imparts a backward and forward motion to a piece in contact with it. The motion imparted to the follower may be at right angles to or parallel with the axis of the cam, or at some other angle.

The motions which cams are designed to give to their followers commonly belonged to one of the following kinds: uniform motion, harmonic motion, or "gravity" motion. The cam may give one kind of motion all the time or it may give different kinds of motion at different stages in its revolution.

Before studying the cams themselves, we will consider the three kinds of motions mentioned.

Uniform Motion. If a body moves through equal spaces in equal intervals of time, it is said to have uniform motion, that is, its velocity is constant.

Harmonic Motion. If a point as C, Fig. 34, travels around the circumference of a circle with uniform velocity, and another point, as E, travels across the diameter at the same time at such a velocity that it is always at the point where a perpendicular let fall from C would meet the diameter, the point E would be said to have harmonic motion. Its velocity will increase from the starting point A until it reaches the center O, and from O to D its velocity gradually decereases to zero at D.

Gravity Motion, or uniformly accelerated and retarded motion, is also a motion where the velocity gradually increases until it reaches a maximum at the middle of the path and from there

gradually decreases to the end. The rate of increase and decrease, however, is different from that in harmonic motion, the velocity being increased in gravity motion, by equal amounts in equal intervals of time, the spaces traveled over in successive intervals of time being in the ratio of 1, 3, 5, 7, etc., to the middle of the path, and decreasing in the same ratio to the end.

The kind of motion which the follower is desired to have must be taken into consideration when designing a cam.

Plate Cams. Fig. 35 shows a plate cam designed to raise and lower the follower P with uniform motion. The point of P is raised from A to *e* while the cam turns right-handed through two-thirds of a revolution, and is lowered again to its original position during the remaining one-third of a revolution of the cam. In this cam the line of motion to the point of P passes through the point O, which is the center of the shaft on which the cam is fixed.

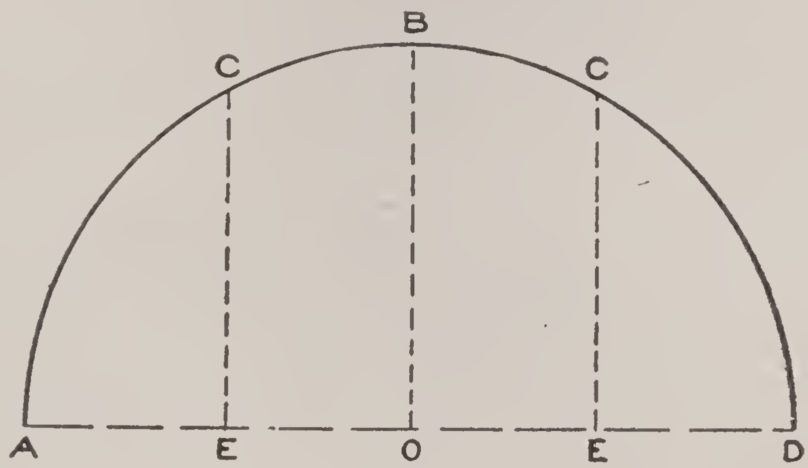


Fig. 34.

To design such a cam, draw a circle with O as a center and passing through A. Since the raising of P is to take place during two-thirds of a revolution, right-handed, find a point E on the circumference of the circle, such that the arc AHE shall be $\frac{2}{3}$ of the whole circumference, thus leaving arc ACE equal to $\frac{1}{3}$ of the circumference. Divide the arc AHE into any number of equal parts and draw the radial lines OF, OG, etc. Divide A*e* into the same number of equal parts and from the points of division 1, 2, 3, etc., thus found, swing arcs around the center O, cutting OF, OG, etc., at points *f*, *g*, etc., respectively. A smooth curve drawn through A, *f*, *g*, etc., to *m*, will give the outline of that part of the cam which raises P. The outline of the rest of the cam is found in a similar manner, by dividing arc ACE into any number of equal

parts and making a new division of A*e* into the same number of equal parts, (points *d*, *c*, *b*.)

Fig. 36 shows a cam which gives the same motion to the follower as was given by the cam shown in Fig. 35, but in this case the line of motion of P, instead of passing through O, passes a distance O*a* to one side of O. The only difference in the method of designing this cam from that previously described is that instead of drawing radial lines through points A, F, G, etc., we draw lines

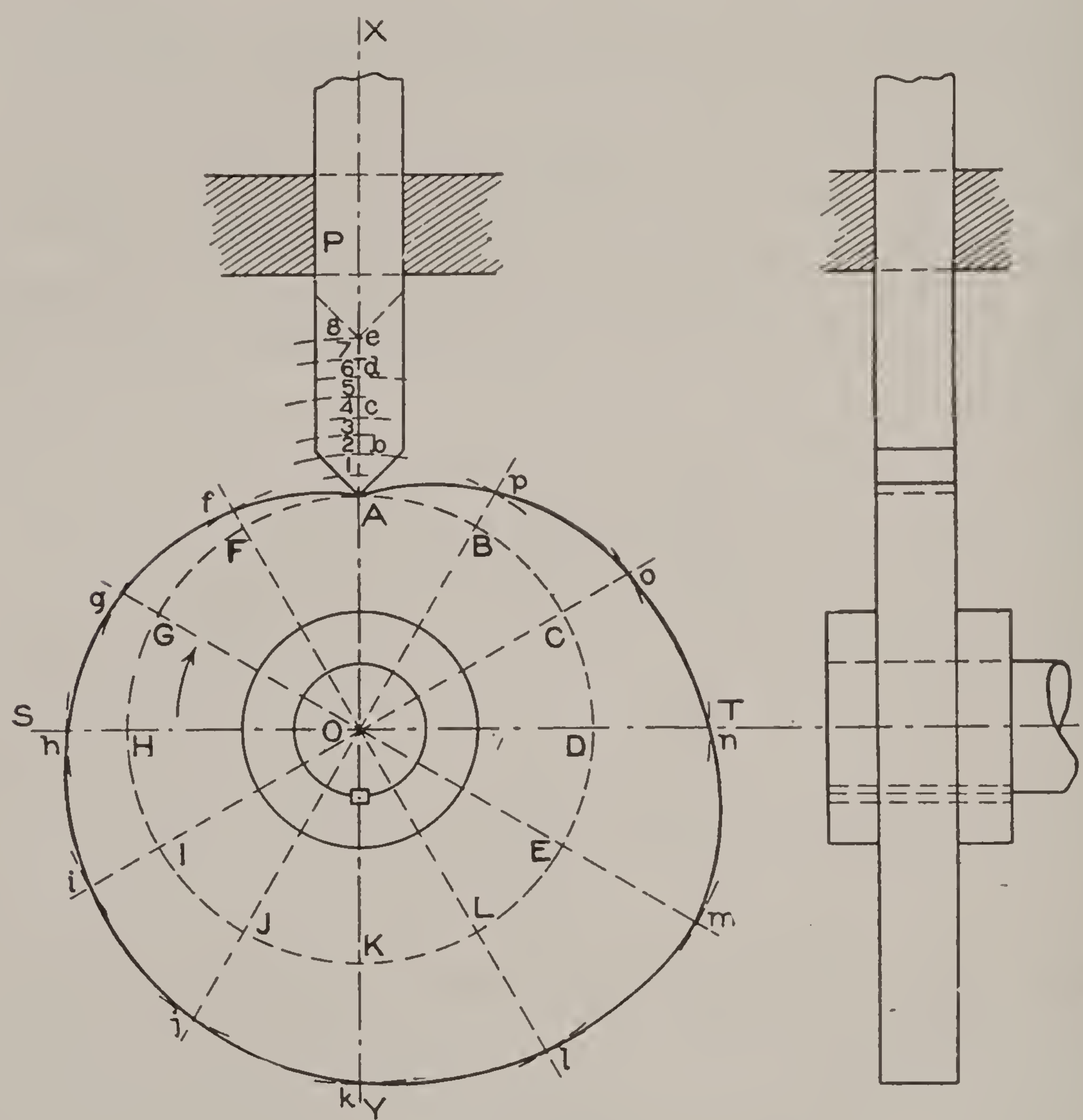


Fig. 35.

through these points tangent to a circle drawn with center O and radius O*a*.

If in Figs. 35 and 36 it had been required to raise P with harmonic motion instead of uniform motion, the only difference in construction would have been in making the divisions of A*e*. These divisions, instead of being equal, would be found as shown on a larger scale in Fig. 37. On the line A*e* as a diameter, draw a semicircle and divide this semicircle into as many equal parts as we divided the arc AHE in Figs. 35 and 36. From the points

BCD, etc. (Fig. 37), draw perpendiculars to line Ae, cutting it at points 1, 2, 3, etc. The division A – 1, 1 – 2, etc., thus found, are the divisions of Ae which would be used in finding the cam outline, in place of the equal divisions which were used for uniform motion.

Fig. 38 shows how Ae would be divided if the motion were

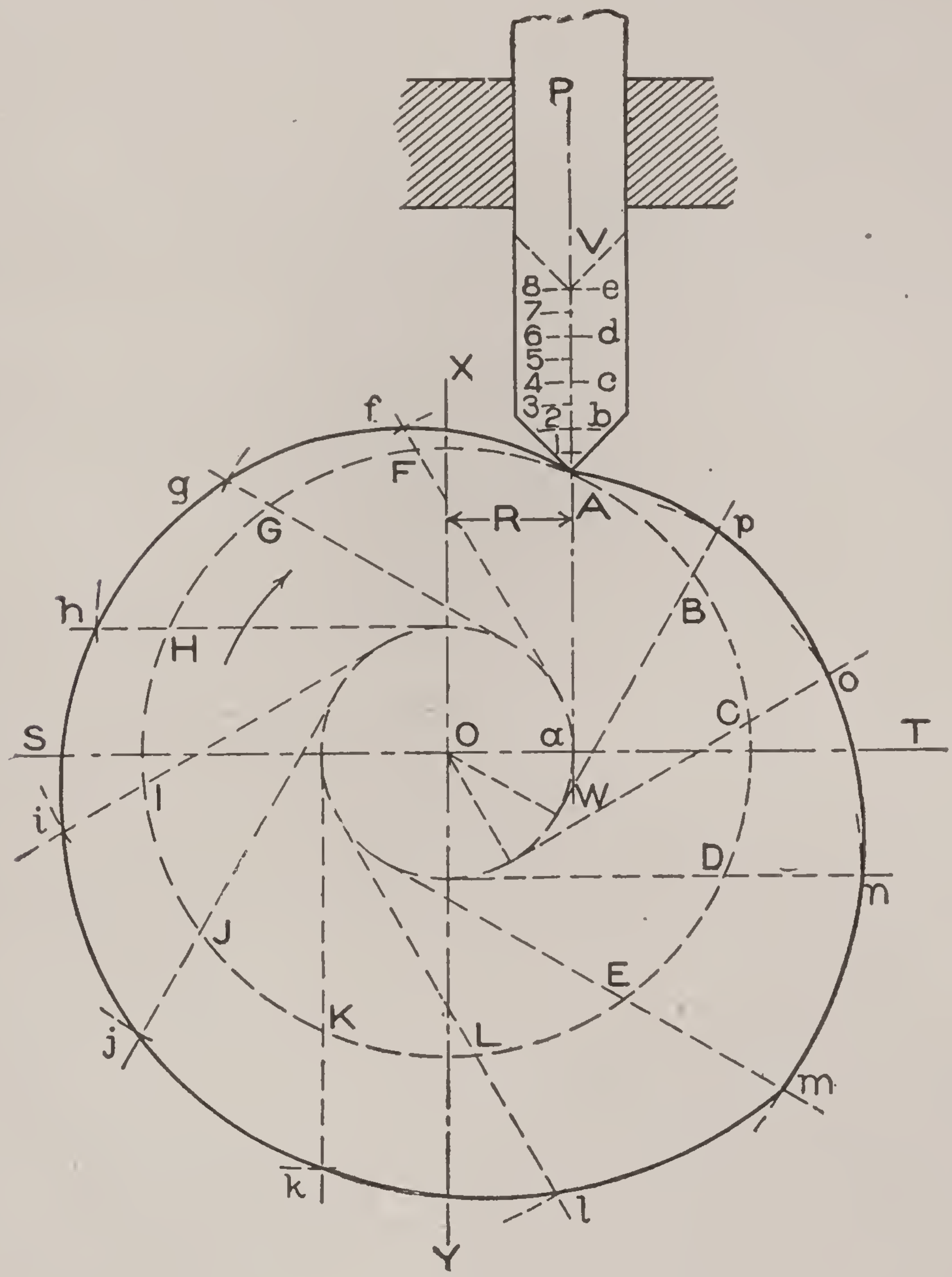


Fig. 36.

to be "Gravity." Since Ae is to be divided into as many equal parts as arc AHE, in this case it will be divided into eight parts. Now if the motion which the cam is to give to piece P is to be uniformly accelerated and retarded (that is, gravity motion), Ae must be divided in such a way that the distance from 1 to 2 is three times the distance from A to 1; the distance from 2 to 3 is five times the distance from A to 1; 3 to 4 is seven times A to

1; 4 to 5 is seven times A to 1; 5 to 6 is five times A to 1; 6 to 7 is three times A to 1; and 7 to e is equal to A to 1. Therefore the whole line Ae is $1+3+5+7+7+5+3+1$ or 32 times the distance from A to 1, or in other words, A–1 is $\frac{1}{32}$ of the whole line Ae, and 1–2 is $\frac{3}{32}$ of Ae, and so on. To divide Ae so that the divisions may bear this relation to each other, draw the line AR at any convenient angle, and choosing any convenient distance as a unit, mark it off on AR thirty-two times, beginning at A. From I, the last of these dividing points, draw a line to e; next find the points B, C, D, etc., as follows: B is the first division from A, C the third from B, etc., thus getting the divisions of A1 in the ratio 1, 3, 5, 7, 7, 5, 3, 1. From the points B, C, D,

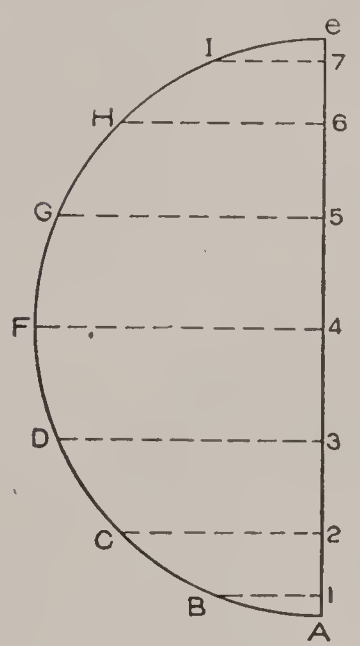


Fig. 37.

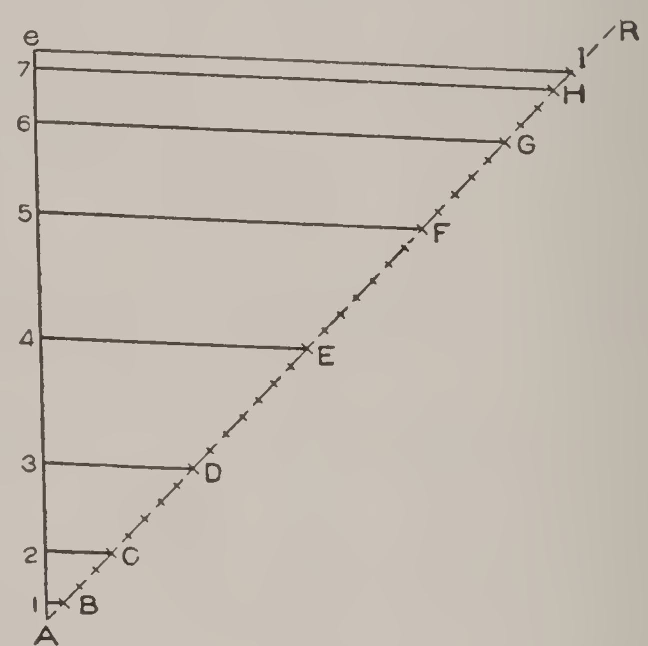


Fig. 38.

etc., draw lines parallel to 1e, meeting Ae at 1, 2, 3, etc., which will be the required points of division.

The cams which we have been considering all act on the comparatively sharp end of the piece P, and consequently much friction and rapid wearing will result if much power is transmitted. Fig. 39 shows a cam designed to act on a roller. The outline is first found for a cam to act on a piece like those in the preceding cases, with its point at the center of the roller. This curve is shown dotted in the figure. Next, with a radius equal to the radius of the roller, and with centers at any number of points around the dotted curve, draw arcs as shown. A smooth curve drawn *tangent* to these arcs will be the outline of the cam which is to act on the roller.

Cylindrical Cams. A plate cam, such as we have been considering, can be designed to give almost any kind of motion in a plane at right angles to the axis of the shaft on which the cam is located, but can not give motion parallel to the axis of the shaft. If, however, we place on the shaft a cylinder with a groove cut in it, the shape of the groove may be made such as to give to a piece inserted in it almost any motion along the shaft; or, if the depth of the groove be varied, the follower may be given a motion which shall be made up of two components, one along the shaft and one at right angles to the shaft.

Fig. 40 shows two views of a cam designed to give a backward and forward motion in a line parallel to the axis of the shaft.

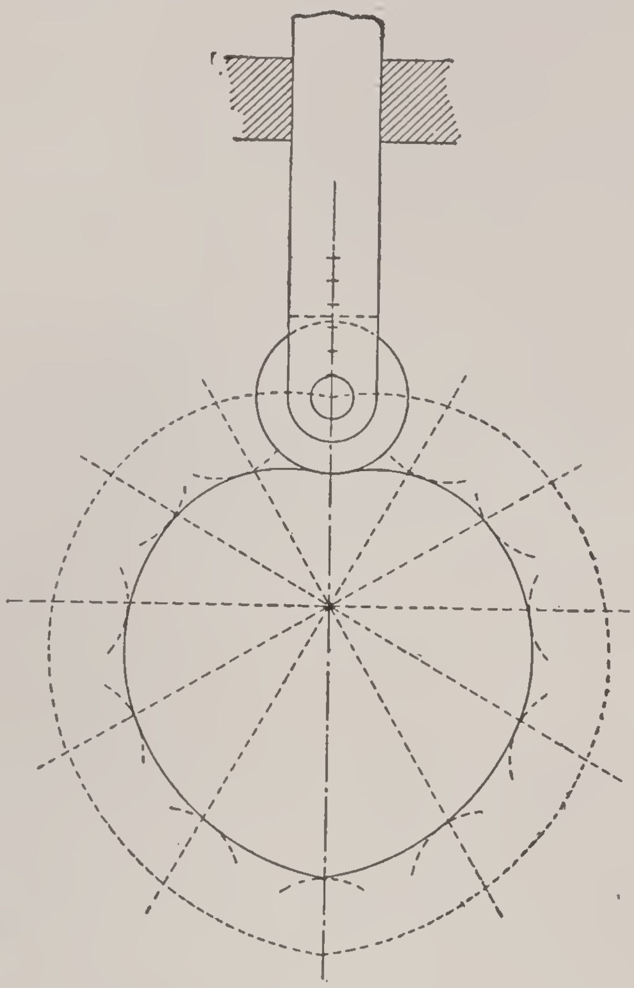


Fig. 39.

Familiar illustrations of the use of plate cams are found in the bobbin-winding mechanism on some sewing machines; on

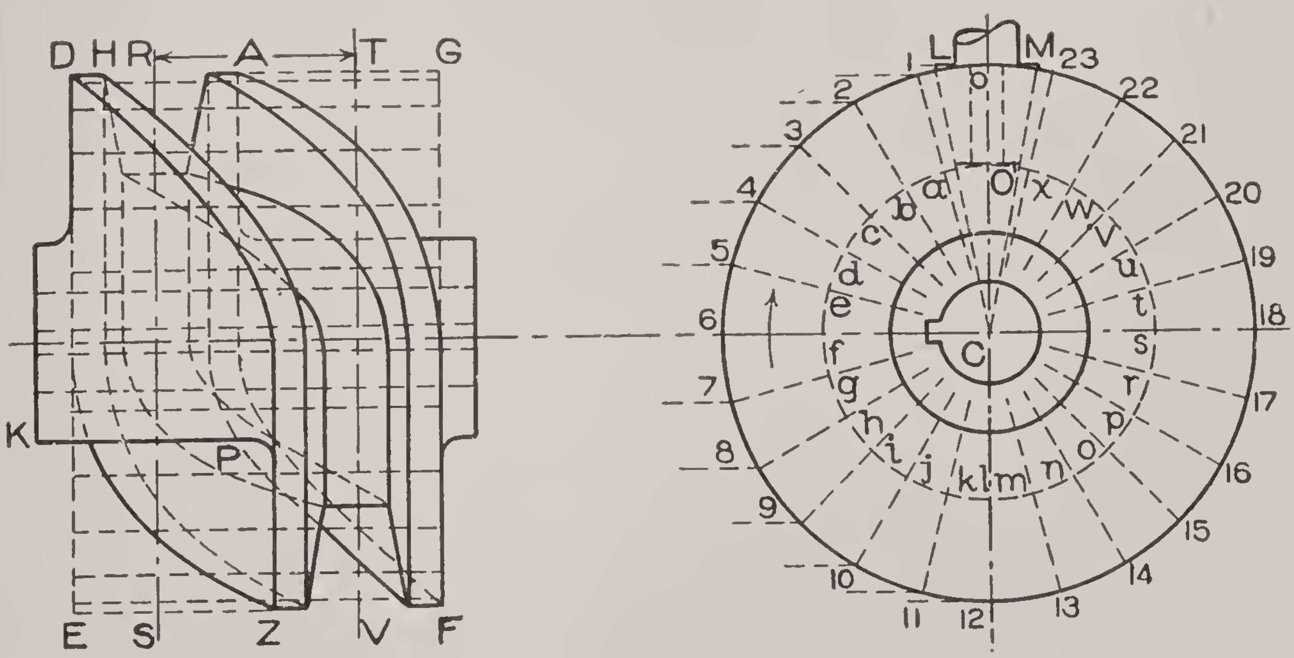


Fig. 40.

many kinds of looms, and in the valve gear on the Brown and other steam engines. Cylindrical cams are used in many places

in textile work and in machine tools. One very common use is in stretchers on many forms of cloth-finishing machinery.

LEVERS.

A lever is a rigid piece supported at some point called the fulcrum, and so arranged that when force is applied at a certain point in the piece, work is done at a certain other point by reason

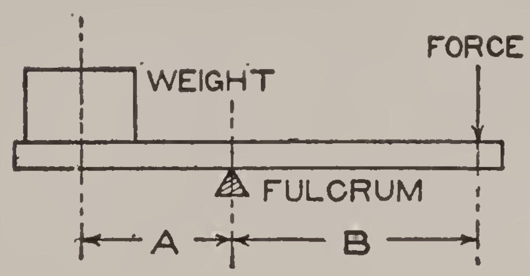


Fig. 41.

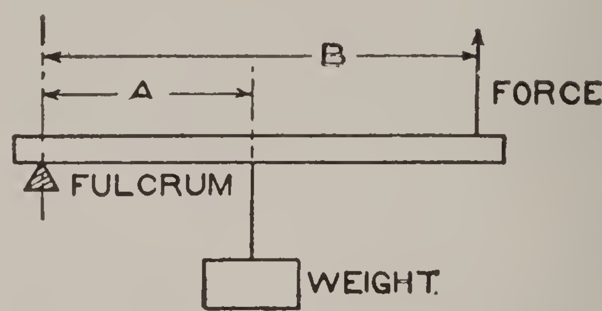


Fig. 42.

of the pivoting action around the fulcrum. Figs. 41, 42 and 43 illustrate the three common kinds of levers, the difference consisting in the relative positions of the force applied and the weight lifted, with respect to the fulcrum. In any of the three cases, if we let F = force applied, W = weight lifted, A = distance from fulcrum to weight, and B = distance from fulcrum to F, we have the following equation:

$$F \times B = A \times W \text{ or}$$

$$\frac{F}{W} = \frac{A}{B} \qquad (16)$$

from which, if any three of the quantities are known, the fourth may be found.

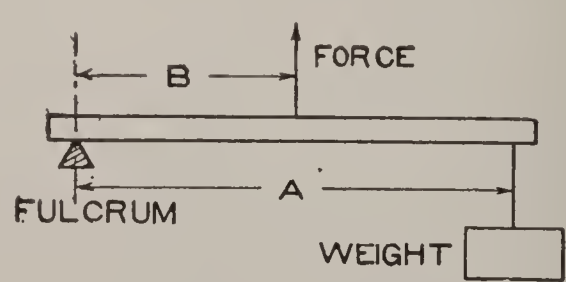


Fig. 43.

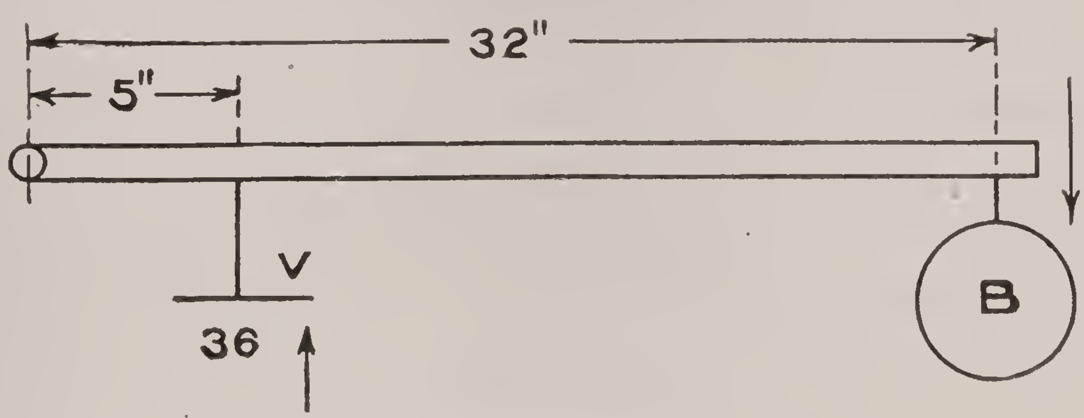
Distance A is called the *weight arm*, and distance B is called the *power arm*. The product of A times the weight is called the moment of the weight, and the product of B times the force is called the moment of the force. Another way of stating the principle expressed in equation (16) is:

Moment of force = moment of weight.

Example: Suppose a weight of 40 pounds is hung on the end of a lever. If the distance from the fulcrum to the weight is 14 inches, what power must be applied to raise the weight, the distance from the fulcrum to the power being 18 inches?

$$F \times B = A \times W$$
$$F \times 18 = 14 \times 40$$
$$F = \frac{14 \times 40}{18}$$
$$= 31.11 \text{ pounds.}$$

Another example: Let the accompanying diagram represent a safety valve. We will neglect the weight of the lever and valve. Suppose the valve V has an area of 3 square inches and the steam pressure per square inch is 36 pounds. The valve is 5 inches from the fulcrum and the weightis 32 inches from the fulcrum. What should be the weight of the ball B?



First, let us find the moment of power. The total upward pressure is $3 \times 36 = 108$, because the total steam pressure equals the pressure per square inch multiplied by the area.

The moment of power is $108 \times 5 = 540$.

The moment of weight is $32 \times B$.

$$\text{Then } 32 \times B = 540$$
$$B = \frac{540}{32}$$
$$= 17 \text{ pounds (nearly).}$$

Had we considered the weight of the valve and lever, we would have added their moments to that of the weight, because these weights increase the weight but not the power.

If in addition to the data given above, the lever weighs 10

pounds and its center of gravity is at its center, that is, 16 inches from the fulcrum. Then

$$\text{Moment of lever} = 10 \times 16 = 160.$$

The valve and valve spindle weigh 8 pounds and are 5 inches from the fulcrum, hence

$$\text{Moment of valve} = 8 \times 5 = 40.$$

$$\text{Total moment of weight} = 32 \times B + 200.$$

The moment of power is, from the previous example, 540, and we have the equation

$$32 \times B + 200 = 540$$
$$32\ B = 540 - 200.$$
$$32\ B = 340$$
$$B = \frac{340}{32} = 10.62 + \text{pounds.}$$

Thus we see that by considering the weight of the valve and spindle and that of the lever, the ball can be reduced in weight from 17 to $10\frac{5}{8}$ pounds.

If the lever is curved as in Fig. 44, the weight arm A becomes the length of the perpendicular from the fulcrum to the line of action of the weight, and the power arm B the length of the perpendicular from the fulcrum to the line of action of the force.

LINK WORK.

Four-Bar Linkage. If we have the four rods AB, BC, CD and DA, Fig. 45, each connected to two of the others by pin and eye joints, each rod becomes what is called a link, and the whole forms a four-bar linkage. If the link AB is fixed in a position (as regards the frame of the machine) the pins at A and B become fixed centers, the links AD and BC become what are called cranks, and the link CD becomes a connecting link or connecting rod. If AD is caused to turn with a uniform angular speed about the pin of A, that is, turning through equal angles in equal periods of time, BC will be compelled to turn with some sort of motion about pin B. Whether BC shall have uniform angular motion and whether it shall make complete revolutions for complete revolutions of AD, will depend upon the relative lengths of the four links.

The center line drawn through the fixed link AB is called the

line of centers, and the center line drawn through the connecting rod CD is called the line of connection. Whatever the relative lengths of the various links, the following law holds true for any position of the linkage.

$$\frac{\text{Angular velocity of crank A D}}{\text{Angular velocity of crank B C}} = \frac{\text{B H}}{\text{A K}} = \frac{\text{B E}}{\text{A E}} \qquad (17)$$

That is, if at any given instant the connecting rod be imagined removed and the cranks continue turning at the same speed at which they were moving when the connecting rod was removed, the number of turns of the cranks in a given period of time would be to each other inversely as the lengths of the perpendiculars drawn from the respective fixed centers to the line of connection, and also inversely as the distances from the fixed centers to the point where the line of connection meets the line of centers. A mathematical proof can be given for this law, but it will not be considered here.

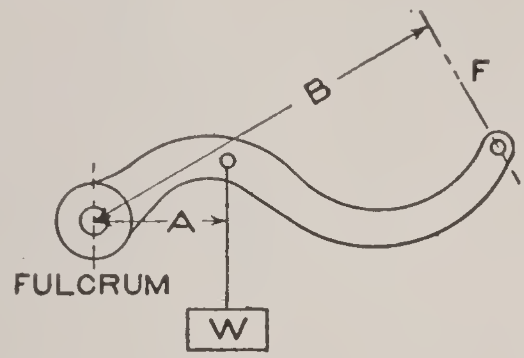


Fig. 44.

If the fixed link AB is made equal in length to the connecting rod DC, and the two cranks are equal (see Fig. 46), the con-

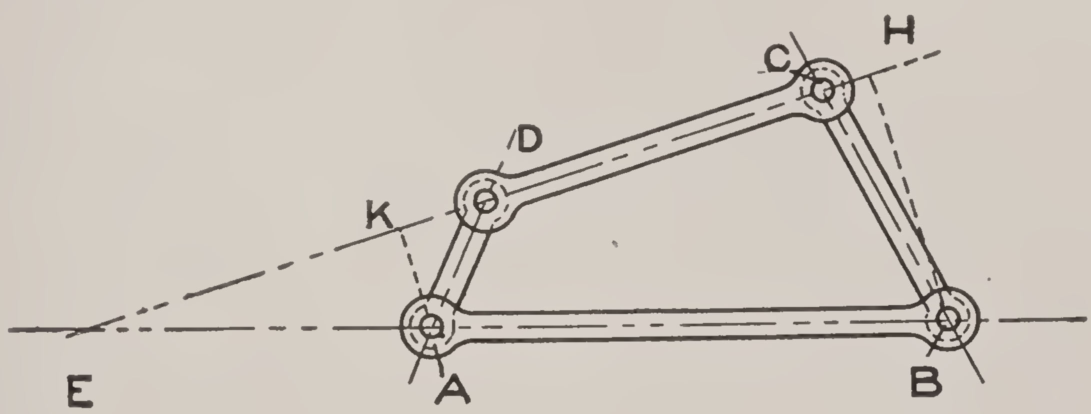


Fig. 45.

necting rod will always be parallel to the fixed link, and the perpendiculars BH and AK will always be equal, so that from equation (17) it will be evident that the speeds of the cranks are always equal. An example of a linkage of this kind is found in the parallel rod connecting the drivers of a locomotive, as shown in Fig. 47. The axles of the drivers form the fixed centers A and B, the

frame of the locomotive forms the fixed link AB, the drivers themselves form the cranks AD and BC, and the parallel rod forms the connecting link.

Crank and Connecting Rod. In the four-bar linkage shown in Fig. 45, the pin C is compelled by crank BC to move on the

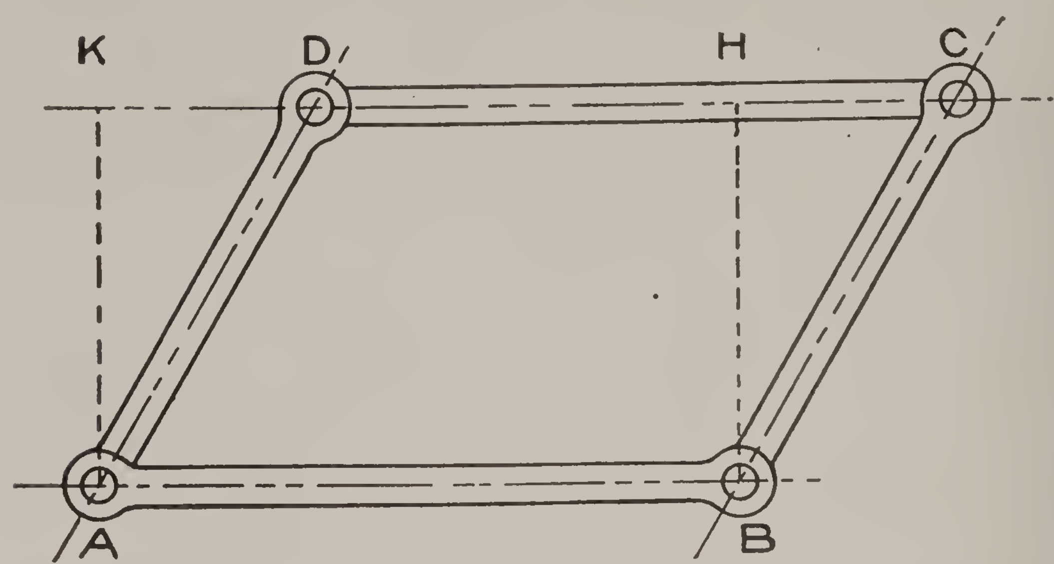


Fig. 46.

arc of a circle whose center is B and radius BC. If in place of BC the fixed link is formed as shown in Fig. 48, being provided with a slot whose radius is BC and center is B, the pin C on the end of the connecting rod will have exactly the same motion that it would if guided by the crank BC. Now, if the radius of the slot

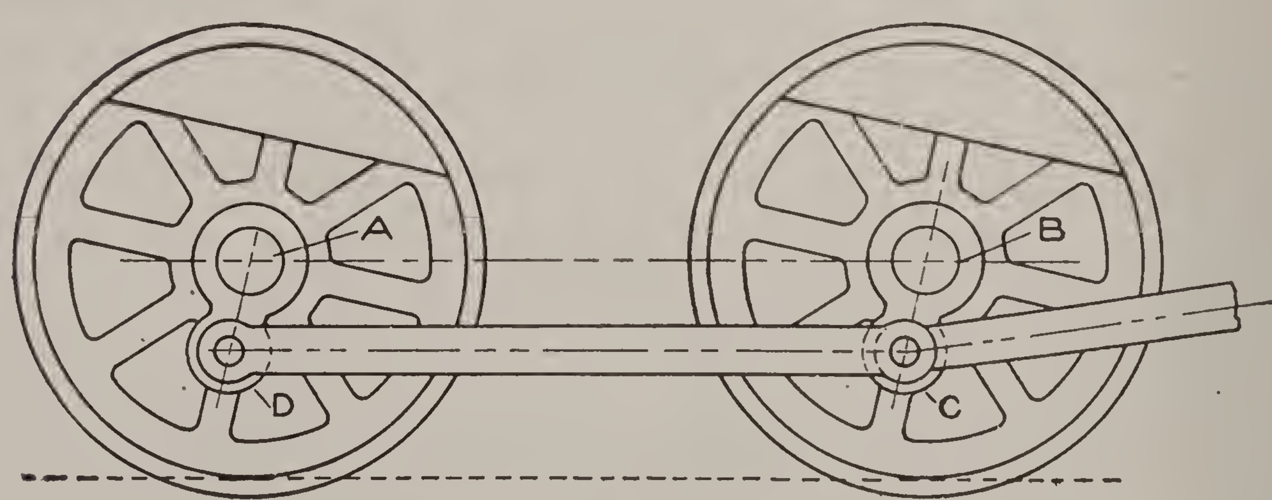


Fig. 47.

is gradually increased, the slot will become nearer and nearer to being straight, so that the linkage shown in Fig. 49, where the slot is straight, may be said to be the limiting case of the linkage shown in Fig. 48. This is the linkage which we have in the crank, connecting rod, crosshead and crosshead guides of a steam engine. The crank shaft corresponds to the pin A, the frame and guides

take the place of the slotted link AC, DC is the connecting rod, and AD the crank.

As there are many problems which may arise in connection with this linkage, particularly as applied to the steam engine, we will consider the most important.

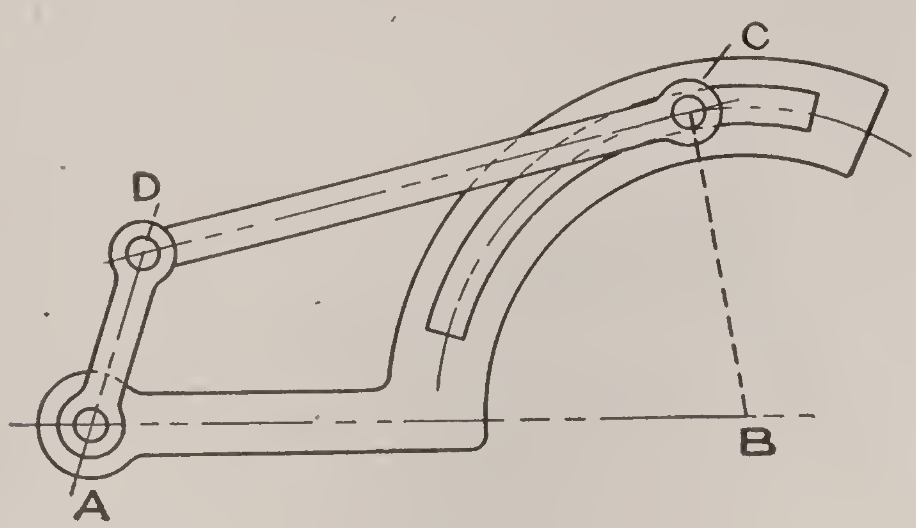


Fig. 48.

Fig. 50 shows the same linkage, the links being represented by their center lines only. AD is the crank, DC the connecting rod, C the crosshead and AC the center line through the crank shaft and the guides.

Suppose the crank has a length R and is making N revolutions per minute at a uniform speed, to find how fast the crosshead is moving at any given position of the crank.

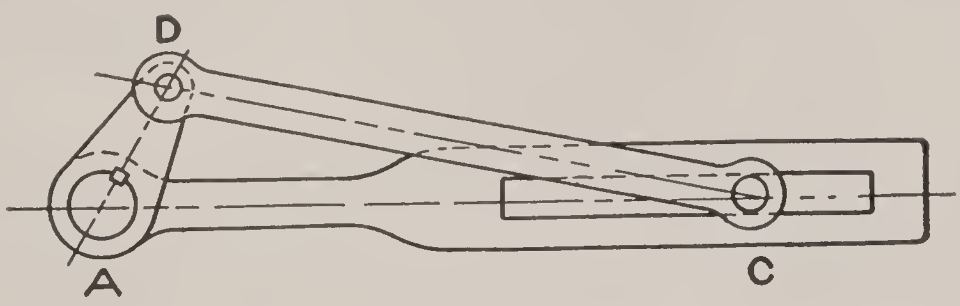


Fig. 49.

We will solve this problem partly graphically and partly by calculation. The first step is to find how fast the crank pin D is moving. For one turn of the crank, D travels through a distance equal to the circumference of a circle whose radius is R, that is, a distance of $2\pi R$. If the crank turns N times per minute the velocity of D must be $2\pi RN$. Knowing the value of R and N, for any particular case we can substite in this formula and find the actual velocity of D. Next draw the linkage at a convenient scale, in the position in which it is desired to find the velocity of C. Draw D*d*

perpendicular to AD and make its length represent at a convenient scale (not necessarily the same scale as was used for the links) the calculated velocity of D. This represents the actual velocity and direction of motion of the end D of the connecting rod at the instant under consideration. Now resolve the velocity D*d* into its components, along and at right angles to DC, by prolonging the

Fig. 50.

line DC and drawing *d*E perpendicular to it. The component DE is the only one which has any effect on the motion of the point C. We have already learned that the motion of the two ends of a rod must have their components along the rod equal, therefore lay off from C, CF = DE. The actual motion of C is along the line CA, and, as CF is one component of the motion, the other component

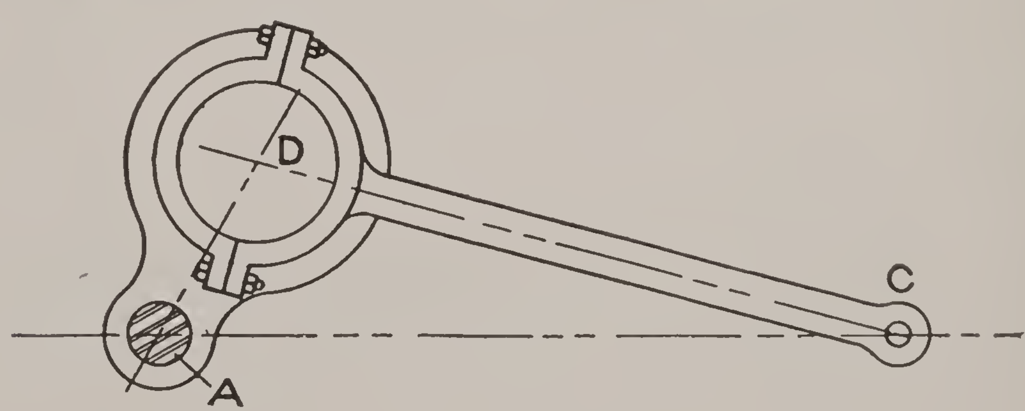


Fig. 51.

must be perpendicular to CF, therefore draw FH perpendicular to CF and meeting CA at H. Then CH is the velocity of point C at the same scale at which D*d* was drawn.

Eccentric. The eccentric and eccentric-rod linkage is in principle the same as the crank and connecting rod. To trace out the connection between the two, let us consider the crank and connecting rod shown in Fig. 51. Here the crank pin D is large and comes almost to the center of the shaft A. By increasing still

further the diameter of the pin D, so that it will take in the shaft, as shown in Fig. 52, we obtain the eccentric.

Considering again the crank and connecting rod linkage: Suppose that in Fig. 53 a force F is applied at the crank pin D in a direction perpendicular to the center line AD; then the pressure which would be exerted by the slide C could be found by the same principle which we have used in previous cases, namely, the forces are inversely proportional to the velocities. Let F be the force at D, and P the pressure at C. Assume any velocity of the point D and represent this at some scale by the line Dd perpendicular to AD. Then find the velocity CH of the point C along the line AC, in the same manner as in Fig. 50. The value of CH can be measured off at the same scale at which Dd was drawn. Then

$$\frac{F}{P} = \frac{CH}{Dd} \tag{18}$$

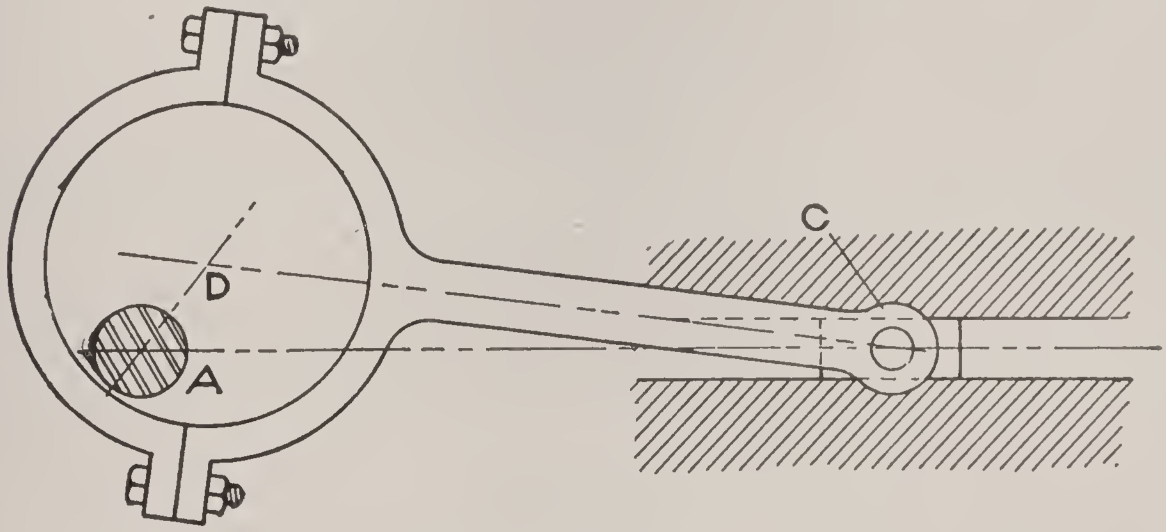


Fig. 52.

from which, if one of the quantities F or P is known, the other may be found.

If the value of CH is found for various positions of AD, keeping Dd constant, it will be seen that the nearer AD comes to coinciding with AC, the smaller CH becomes, and from equation (18) it will appear that the smaller CH is, the greater P becomes with relation to F. The above discussion will hold true if the force acts in the direction Dd or in the opposite direction.

The linkage used in this way to effect pressure at c by a force on D is known as the *toggle joint*, and is used with more or less modification in several kinds of machinery, such as punching machines, brakes on the drivers of a locomotive, etc. The force need

not be applied at D, but may be applied at some other point on AD, or on some piece rigidly connected to AD but making an angle with it. This is shown in Fig. 54. Here the force is applied at E, and we can find the force at C by the same principle as before: The force at C is to force at E inversely as the velocities of C and E.

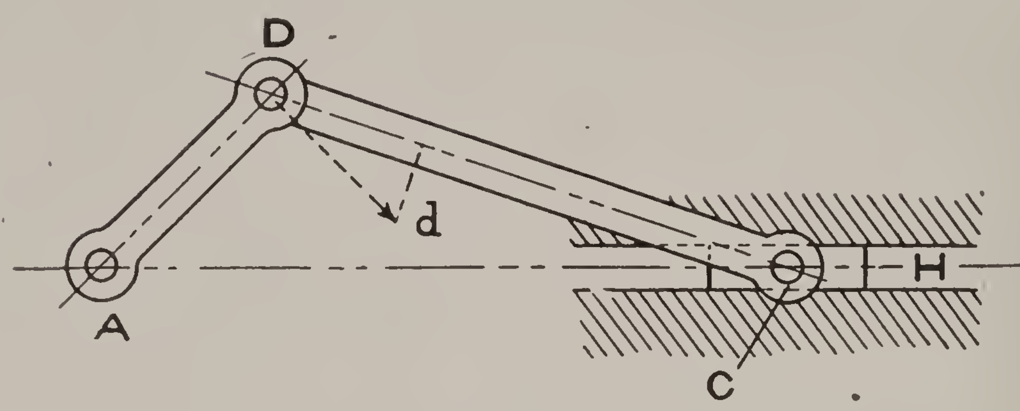


Fig. 53.

The only difference is in finding the velocity of C. Assume a velocity for E, as Ee. Then

$$\frac{\text{Velocity E}}{\text{Velocity D}} = \frac{AE}{AD} \tag{19}$$

from which the velocity of D may be found; the rest of the solution would be the same as for Fig. 53.

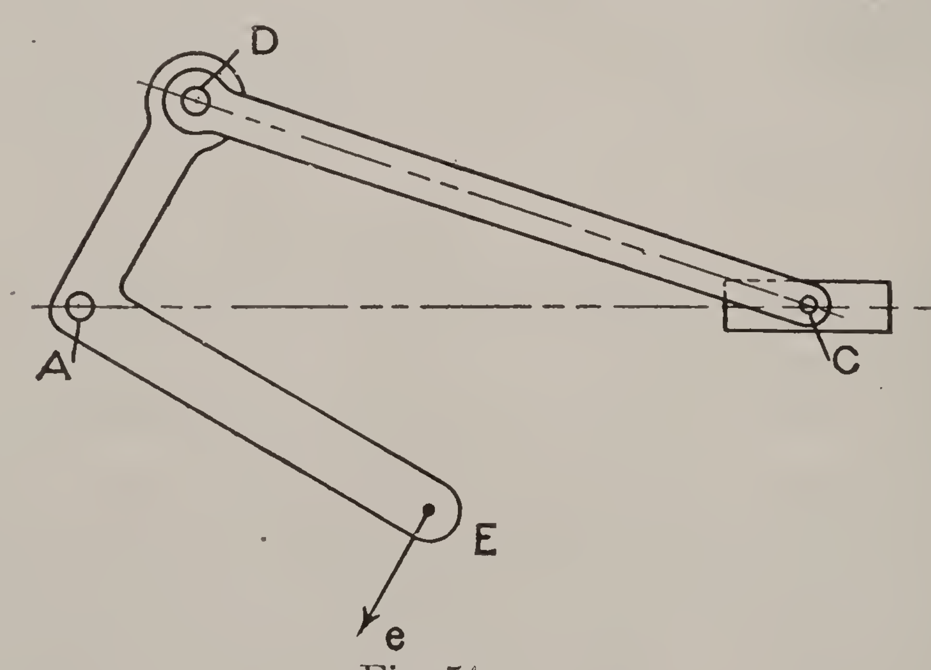


Fig. 54.

These problems may be solved by another and perhaps somewhat shorter method, but, as this would involve the resolution of forces, which have not yet been taken up in detail, we will confine ourselves to the above method.

QUICK RETURN MOTIONS.

In various kinds of machinery, particularly machine tools, it is desired to move a piece backward and forward; the forward motion being slow and the return motion more rapid. Take for example the shaper; as the tool when moving forward is cutting metal, it should go slowly and steadily, but after the cut is made it is desirable to get the tool back ready for its next stroke as quickly as possible. Many different devices are used to accomplish this result.

If in Fig. 45 we replace the connecting rod DC by a slot in the link BC, we get the linkage shown in Fig. 55. A and B are the fixed centers, AD is the driving crank (which usually turns

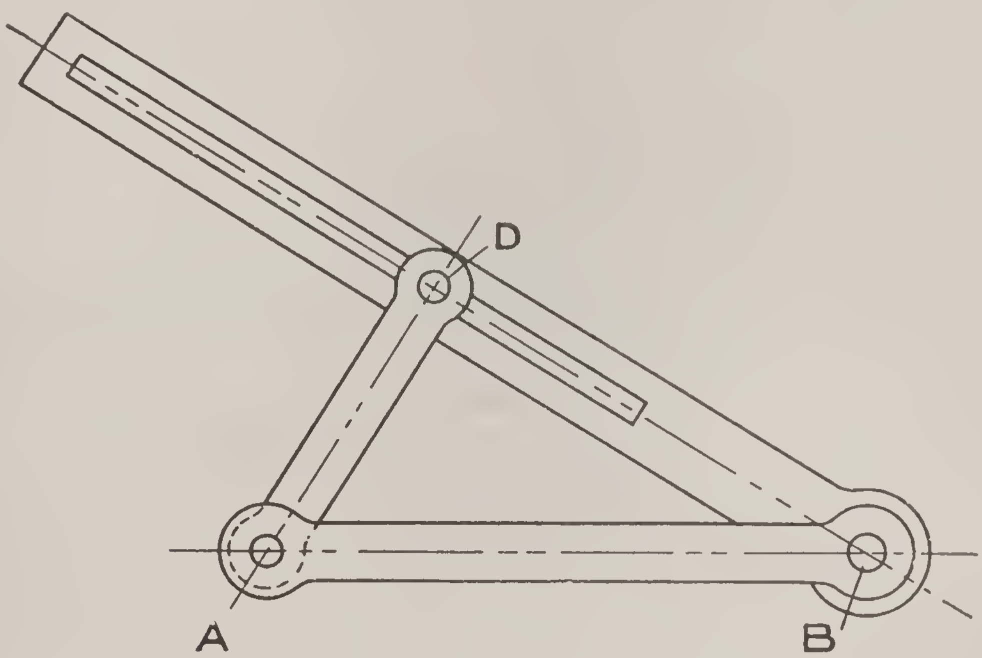


Fig. 55.

with uniform speed), BD is the slotted crank and to some part of BD a link or some other piece is connected by means of which the tool is driven. Two distinct mechanisms are formed, depending upon the relative lengths of the links. If the proportions are such that a circle drawn around the center A, with radius AD, falls outside the center B, as shown in Fig. 56, we have what is known as a Whitworth quick return motion. Here the slotted crank makes one complete revolution for each complete revolution of AD, but its speed is not uniform. In this figure, a connecting rod PT is represented as attached to a point P on the slotted link. The other end of this connecting rod moves the tool holder T along the straight line BT. When the linkage is in the position shown, T is in its extreme right-hand position, and it will be in its

extreme left-hand position when BP occupies the position BP_1. In turning BP through this angle (180°), AD has turned through the angle L. In returning BP to its right-hand position again, AD has to turn through the angle M only. Now, since AD turns with uniform speed and since angle M is less than angle L, T makes its stroke from left to right in less time than was required to move from right to left. The time of advance and time of return are in the ratio of angles L and M. If the length of the crank AD and the ratio of time of advance to return are known the distance AB may be found as follows:

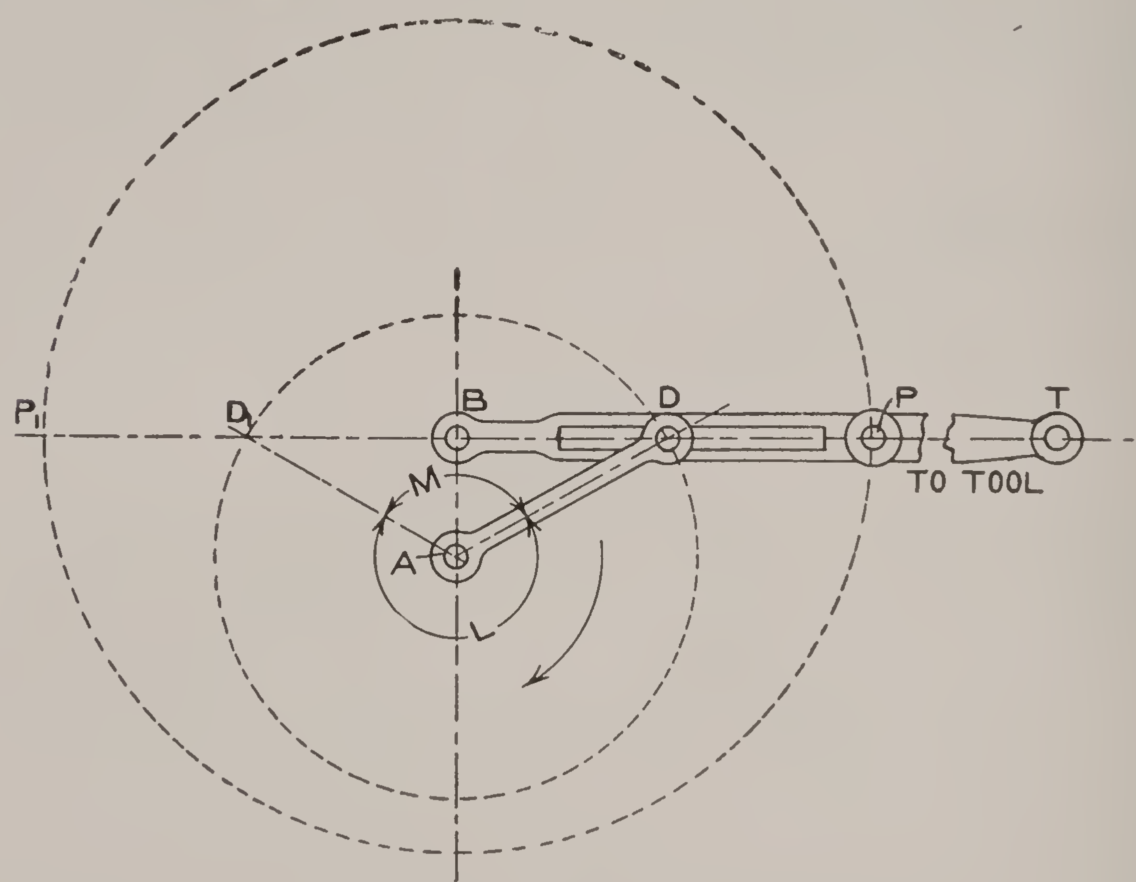


Fig. 56.

With A as a center and AD as a radius, draw a circle and divide the circumference by the points D and D_1 so that angle L may bear the same ratio to angle M that the time of advance bears to the time of return. Join D and D_1 and from A draw a line perpendicular to DD_1, meeting it at B, which will be the required center for the driven crank.

The distance BP governs the length of the stroke of the tool, so that by varying the position of P the length of the stroke may be varied.

If the proportions of the linkage are such that a circle drawn with A as a center and a radius AD comes inside the point B,

that is, if AD is less than AB, we have what is known as a swinging block linkage. Fig. 57 shows this form of quick return motion. The piece which drives the tool is attached to the slotted link at P, which may be anywhere along the link. The linkage is shown at the extreme right of its stroke, the point D being at the point where the center line of the slot is tangent to the circle drawn with center A and radius AD, (that is, the length of the driving crank). AD_1 is the corresponding position of the crank

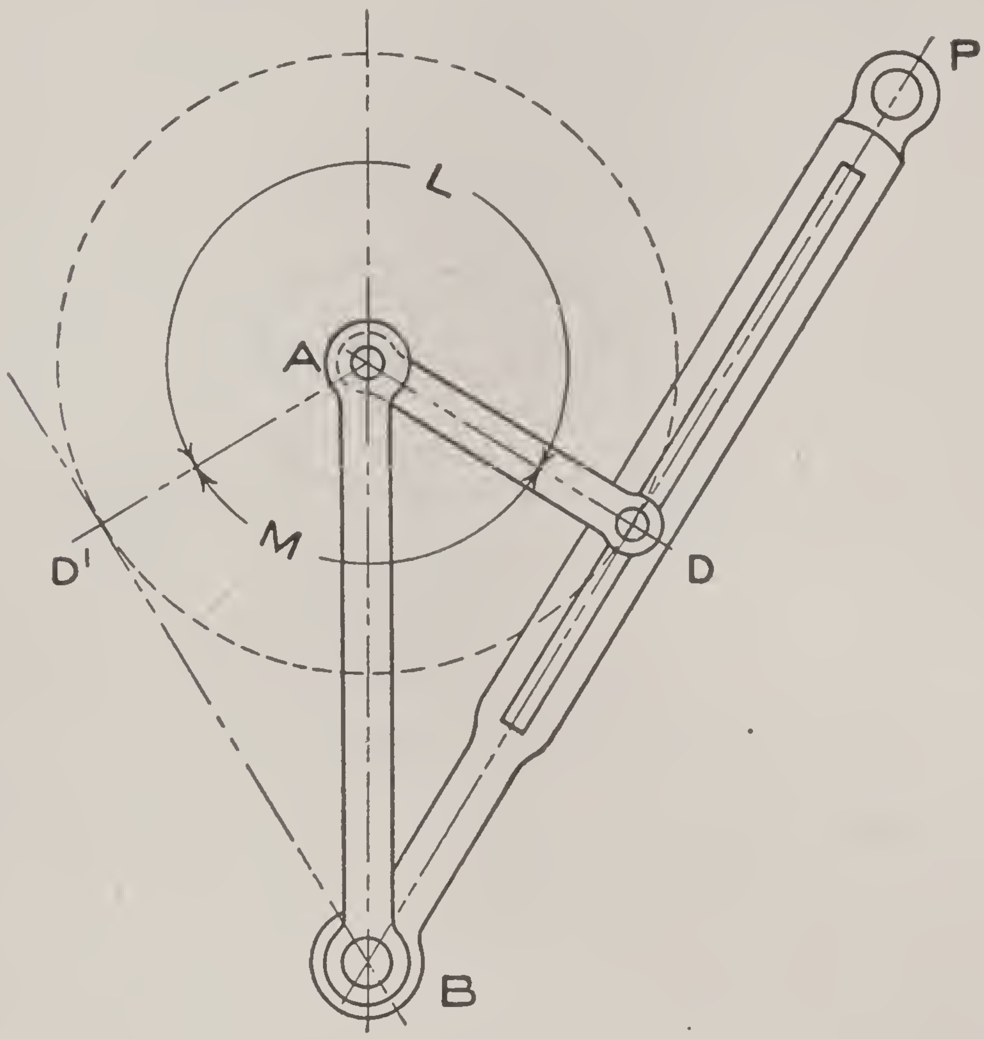


Fig. 57.

at the other extreme of the stroke. The time of advance is to the time of return as angle L is to angle M, as in the case of the Whitworth quick return. If the ratio of advance to return and the length of AD are known, the position of B may be found by drawing the circle with center A and radius AD, and on this circle finding points D and D_1 such that the angles L and M shall have the required ratio. Then draw DB and D_1B tangent to the circle at D and D_1 respectively, meeting each other at B, which is the required center for the driven crank.

GEARING.

If shaft B, Fig. 58, has fastened to it a disc with smooth circumference, the disc being in contact at the point P with another disc on shaft A, the rotation of one shaft will cause the other to rotate, provided there is sufficient friction between the two surfaces to prevent slipping. According to the principles which we have already learned, the following equation will hold true:

$$\frac{\text{Revolutions per minute of A}}{\text{Revolutions per minute of B}} = \frac{\text{B P}}{\text{A P}}$$

In practice, the friction would not be sufficient to be relied upon, so that discs having teeth upon their circumference are used, instead of the plain discs. The discs or wheels thus formed are called gears. The teeth may have any one of several forms, and the gears may connect shafts which are parallel, intersecting at some angle, or neither parallel nor intersecting. Two gears such as shown in Fig. 59, where the shafts are parallel and the teeth on the circumference are parallel to the axis of the gear, are called **spur gears.**

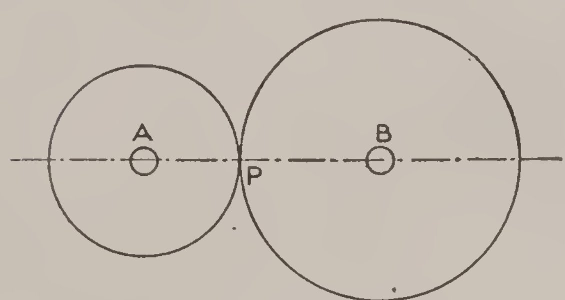


Fig. 58.

The two dot and dash circles drawn about the centers A and B and in contact at P correspond to the two discs of Fig. 58, and the gears may be said to be derived from these circles, which are called the **pitch circles.** The diameters of these circles are called the **pitch diameters** of the gears. The point P, where the two pitch circles touch each other, is called the *pitch point.* Circles drawn through the outer ends of the teeth are called the *addendum cirles,*. and circles drawn at the bottom of the teeth are called the *root circles.* These circles are indicated on the figure. That part of the tooth outlined between the pitch circle and the addendum circle, as PE, is called the **face** of the tooth, and that part between the pitch circle and the root circle, as PF, is called the **flank.** The radius of the addendum circle minus the radius of the pitch circle is called the addendum distance, or simply the *addendum.* The radius of the pitch circle minus the radius of the root circle is called the *root distance* or the *root.* The root is commonly

made a little greater than the addendum, so that when two gears have their pitch circles in contact, if their teeth are of equal length they will not touch bottom, but will have some clearance. The distance from the center of one tooth to the center of the next, measured on the pitch circle, as GH, is called the **circular pitch,** or **circumferential pitch,** and is equal to the circumference of the pitch circle divided by the number of teeth.

In order to run together, two gears must have the same circular pitch. The number of teeth on two gears of the same pitch are proportional to the circumferences, and, consequently, to the diameters of their pitch circles; and as the speeds of the two shafts

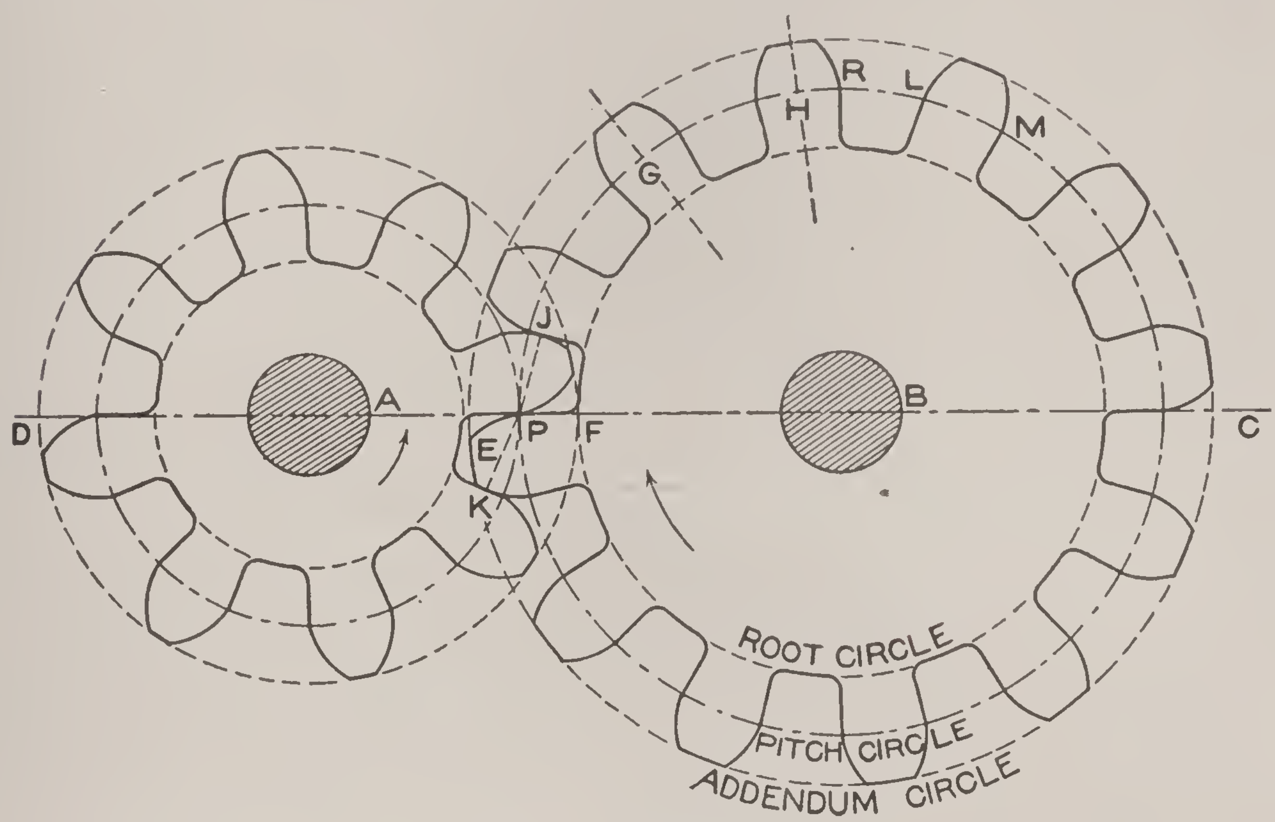


Fig. 59.

which are connected by a pair of gears are inversely proportional to the diameters of the pitch circles of the gears, the speeds must also be inversely proportional to the number of teeth.

On rough gears the width of the tooth LM is made a little less than the width of the space RL, to allow for irregularity of construction. The difference in the width of the two is called the *back lash.*

Although the circular pitch is a term which is frequently used in connection with gearing, there is another kind of pitch which is often used. This is the **diametral pitch,** and is equal to the diameter of the pitch circle divided by the number of teeth, or, in other words, the amount of pitch diameter allowed for each

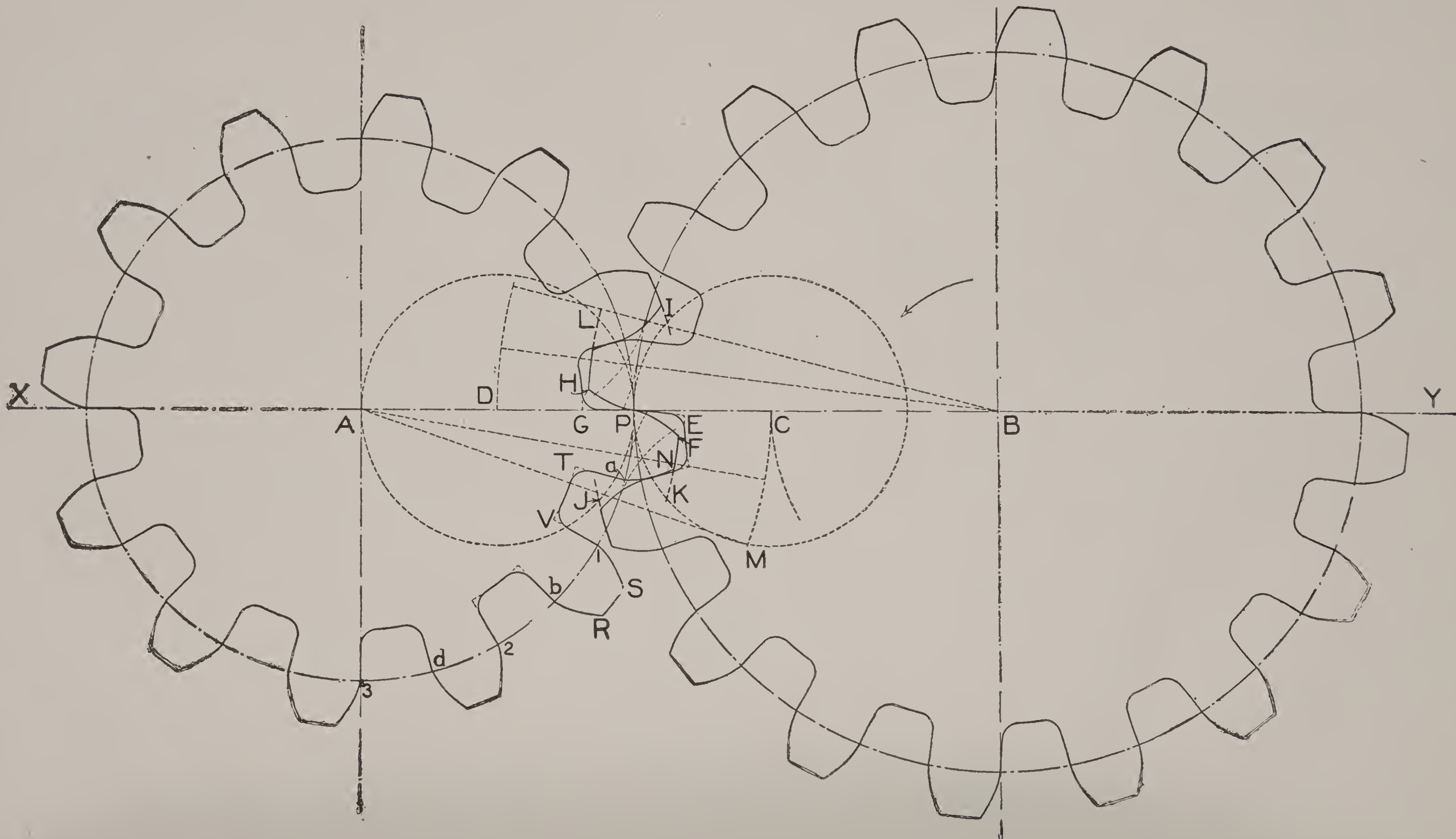


Fig. 60.

tooth. The diametral pitch bears the same relation to the circular pitch that the diameter of a circle bears to its circumference; that is, the diametral pitch is equal to the circular pitch divided by π. In speaking of the pitch of a gear, instead of using the diametral pitch, which is often a fraction, it is customary to use only the denominator of the fraction. For example, if the diametral pitch is $\frac{1}{2}$ inch, it would be spoken of as a 2-pitch gear. This would be the same as saying that for every inch of pitch diameter there are two teeth.

Problems similar to the following often arise in this connection:

1. Given two gears, 4 pitch, having 12 teeth and 16 teeth respectively, to find their pitch diameters and the distance apart that their centers should be located, to run properly.

Since they are 4 pitch, their diametral pitch is $\frac{1}{4}$ inch and their pitch diameters will be their numbers of teeth multiplied by $\frac{1}{4}$, so that one would be $12 \times \frac{1}{4} = 3$ inches in diameter, and the other $16 \times \frac{1}{4} = 4$ inches in diameter. The distance on centers will be the sum of their pitch radii $= \frac{3}{2} + \frac{4}{2} = 3\frac{1}{2}$ inches.

2. Given two gears, 8 pitch, having diameters 6 and 10 inches respectively, to find the number of teeth.

The expression "8 pitch," besides meaning that the diametral pitch is $\frac{1}{8}$ inch, means that there are 8 teeth for every inch of diameter, so that one gear will have

$$8 \times 6 = 48 \text{ teeth}$$

and the other $8 \times 10 = 80$ teeth.

Referring again to Fig. 59: If gear A is driving the other gear in the direction indicated, there is a working point of contact between the teeth of the two gears at J and another at K, and as the gears turn and the teeth slide along each other, the point where a pair of teeth is in contact changes. If from the point of contact, as J, a line is drawn to the pitch P, the tooth curves should have such form that this line is normal to both curves at J; that is, PJ should be perpendicular to a line drawn tangent to both curves at J. This condition should hold, wherever the point of contact may be, in order that the gears may run smoothly.

There are two kinds of curves which are commonly used for the outlines of gear teeth, and which fulfill the above conditions.

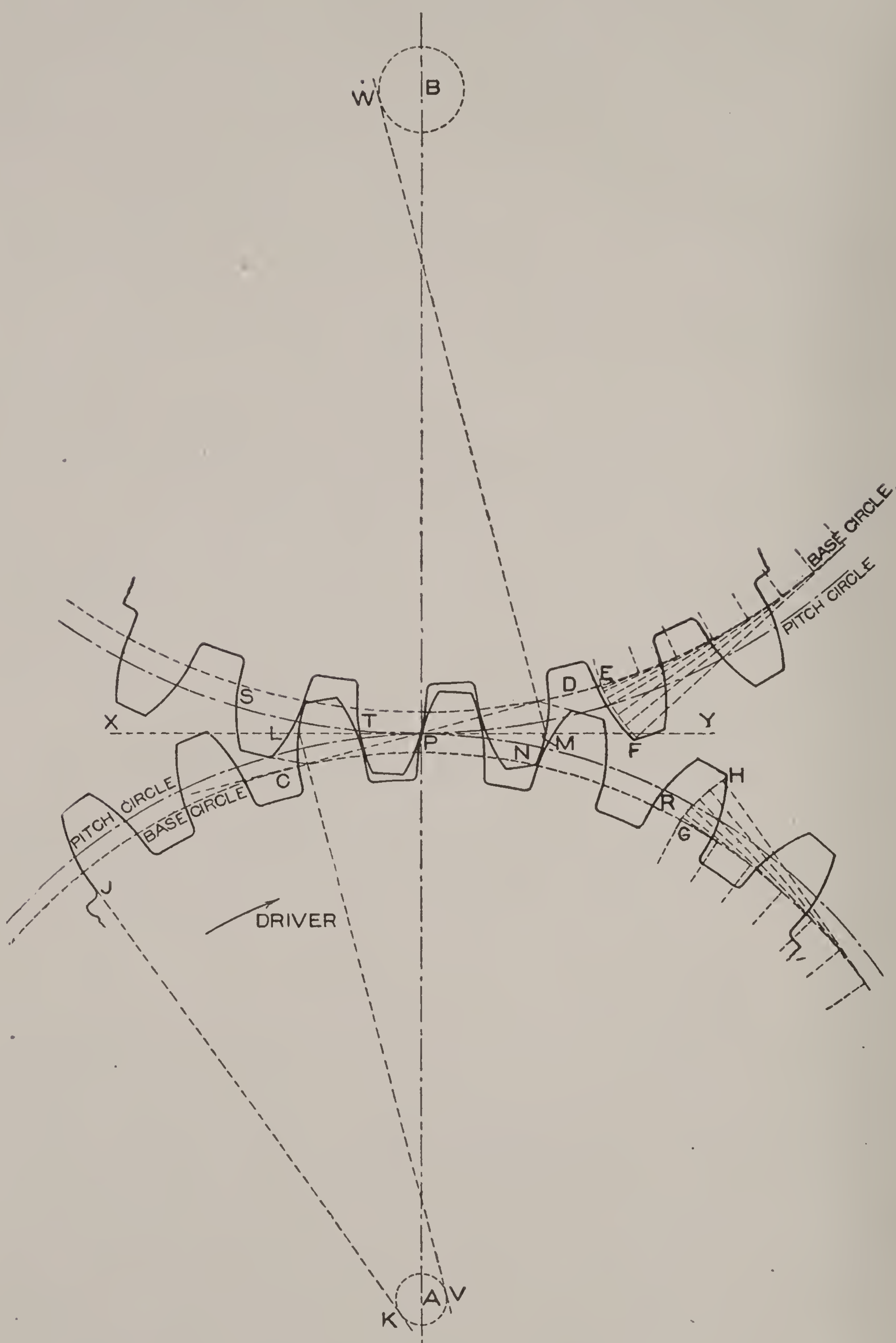

W
B
BASE CIRCLE
PITCH CIRCLE
S
T
D
E
X
L
P
N
M
F
Y
C
H
R
G
PITCH CIRCLE
BASE CIRCLE
J
DRIVER
K
A
V

Fig. 61.

These are the **involute** and the **epicycloidal** curves. Fig. 60 shows a pair of gears with epicycloidal teeth and Fig. 61 shows parts of two gears with involute teeth. The construction for getting the tooth outlines is shown in the figures, but as this properly comes under the subject of drawing, and is not essential to an understanding of gears in general, it will not be explained here.

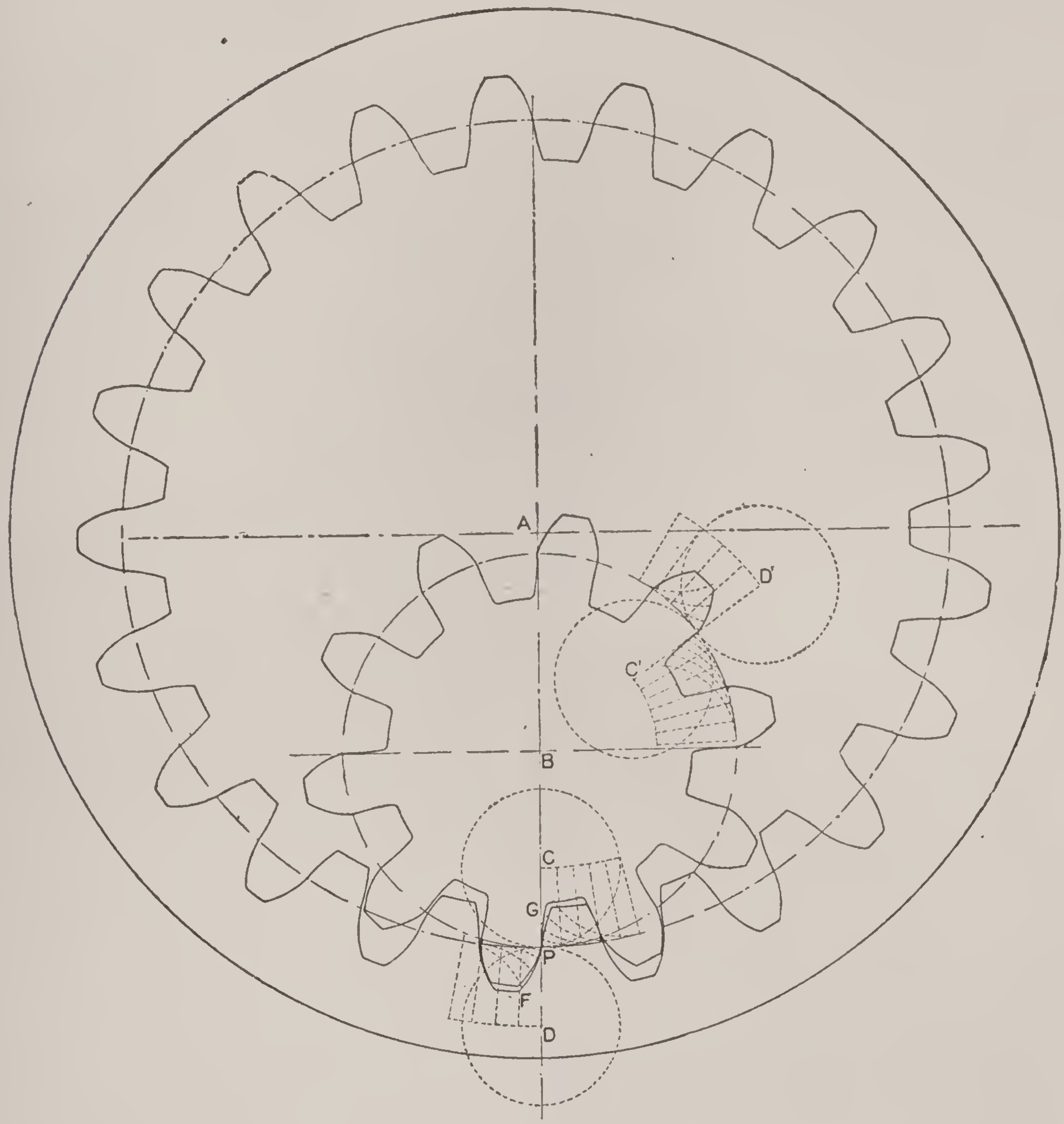


Fig. 62.

Annular Gears. An annular gear is a ring with teeth on its inside edge. Fig. 62 shows such a gear with center at A, meshing with a small spur gear called the pinion.

Rack and Pinion. A rack is a gear whose pitch line is a straight line instead of a circle. Fig. 63 shows an epicycloidal rack in gear with a pinion.

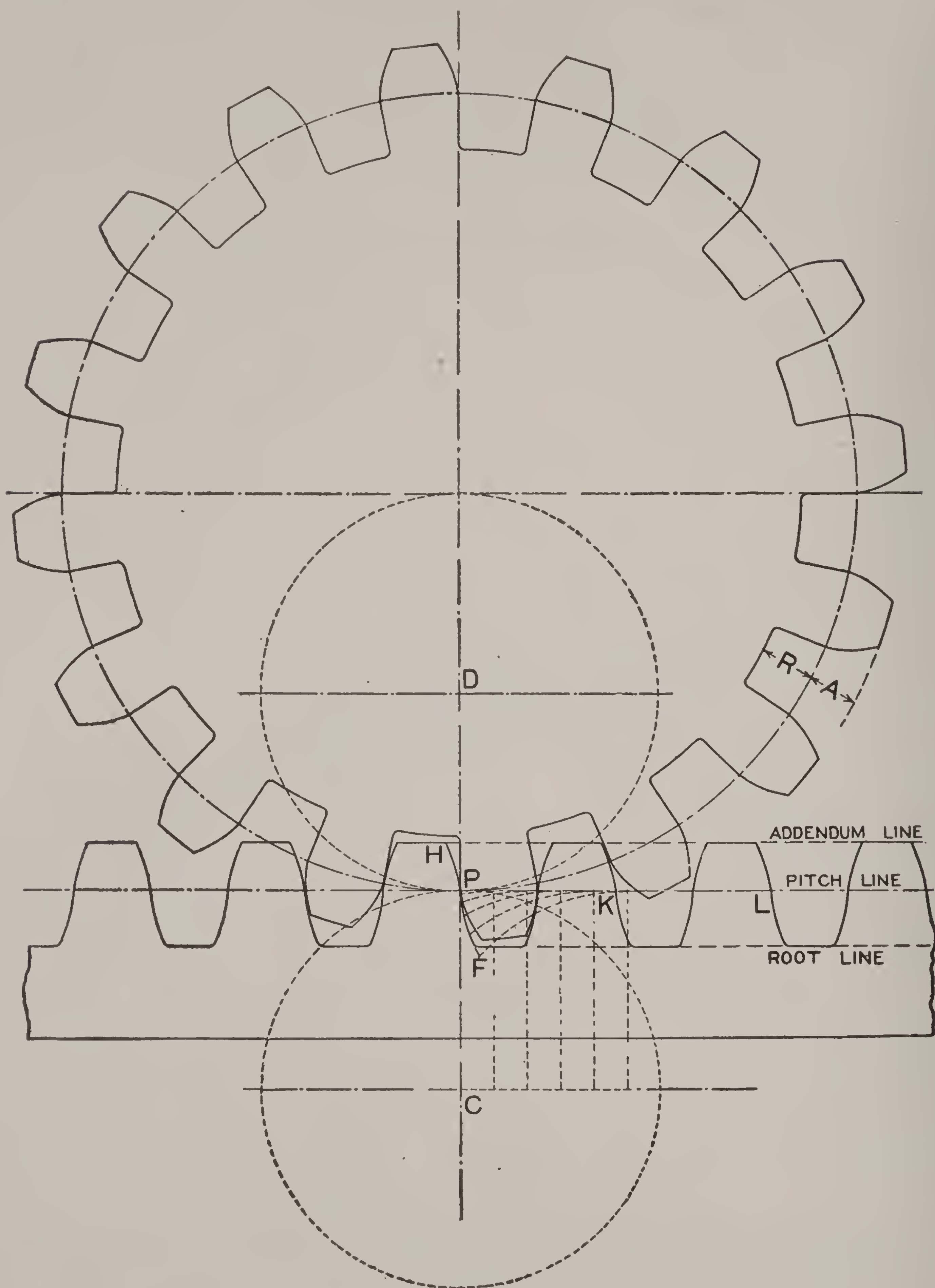


Fig. 63.

Bevel Gears. When two shafts whose axes intersect are to be connected by gears, the gears commonly used are called bevel gears. The theoretically correct pitch surface of a bevel gear is a part of the sector of a sphere, but as the designing and making of such a gear is somewhat difficult, a cone is substituted for a sphere. Fig. 64 shows a pair of bevel gears connecting two shafts

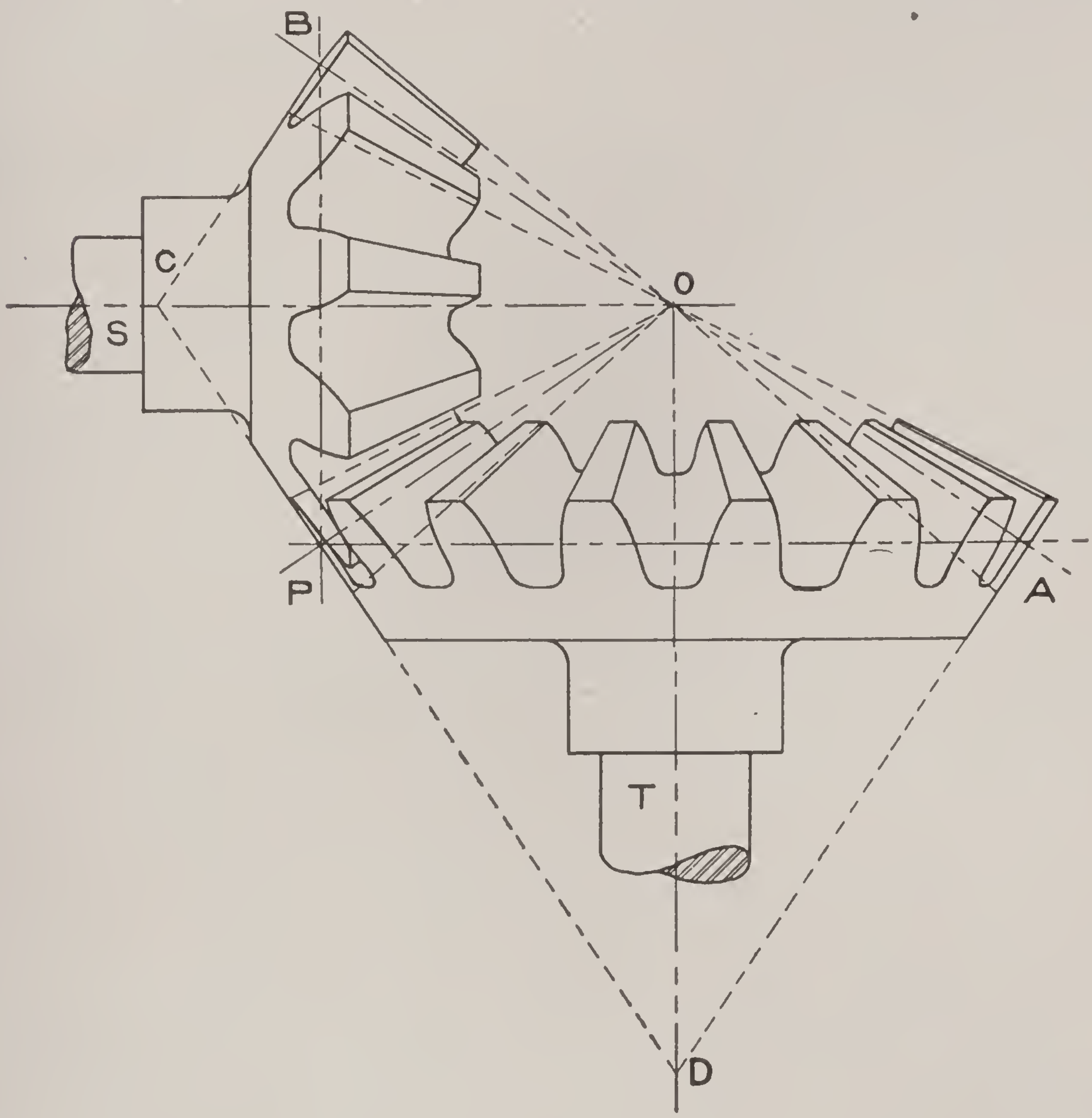


Fig. 64.

which are at right angles. O is the point where the center lines of the shaft intersect, OPA and OPB are the *pitch cones* of the gears, AP and BP the pitch diameters.

The speed of the shaft S is to the speed of the shaft T as AP is to BP. The teeth may be epicycloidal or involute, and the shafts may be at right angles or at some other angle.

Trains of Wheels. Thus far both in gearing and in pulleys and belts, we have considered only one pair of wheels, one being on the driving shaft and the other on the driven shaft. It very

often happens that the connection cannot be made directly by one pair of wheels, either because the shafts are not conveniently placed with relation to each other, or because the diameters cannot be so proportioned as to give the desired speed. In such cases the connection may be made by a train of pulleys or a train of gears. Fig. 65 shows a train of pulleys, and Fig. 66 a train of gears.

In Fig. 65 shaft A drives shaft B by means of pulleys E and F. B in turn drives C by means of pulleys G and H, and C drives D by pulleys J and K.

Assume shaft A to make 100 R. P. M. and the pulleys of the following diameters:

E = 36 inches	G = 24 inches	J = 20 inches
F = 12 inches	H = 18 inches	K = 10 inches,

to find the number of revolutions of shaft D. Applying the principles which we have already learned,

$$\frac{\text{R. P. M. of B}}{\text{R. P. M. of A}} = \frac{\text{Diameter of E}}{\text{Diameter of F}} \quad \text{or}$$

$$\text{R. P. M. of B} = \text{R. P. M. of A} \times \frac{\text{diam. of E}}{\text{diam. of F}} = 100 \times \tfrac{36}{12}$$

$$\text{In like manner R. P. M. of C} = \text{R. P. M. of B} \times \tfrac{24}{18}$$
$$= 100 \times \tfrac{36}{12} \times \tfrac{24}{18},$$

$$\text{and R. P. M. of D} = \text{R. P. M. of C} \times \tfrac{20}{10}$$
$$= 100 \times \tfrac{36}{12} \times \tfrac{24}{18} \times \tfrac{20}{10}$$
$$= 800.$$

It will be noticed that pulleys E, G and J are drivers and F, H and K are driven pulleys, so that the above may be stated thus:

Revolutions of last shaft (or last wheel) = revolutions of first shaft (or first wheel) multiplied by a fraction whose numerator is the product of the diameter of all the *driving* pulleys, and whose denominator is the product of the diameters of all the *driven* pulleys. **(20)**

The same rule will apply to the train of gears in Fig. 66, if we use either the pitch diameters or the number of teeth in the respective gears where diameters are used instead of the pulley diameters.

In Fig. 65, where all the belts are open belts, all the shafts

turn in the same direction; but where two shafts are connected by a pair of spur gears, the shafts turn in opposite directions, so that, in Fig. 66, the direction in which shaft D will turn with reference to the direction of A, will depend upon the number of gears in the train. The best way to determine this is to follow the train through, putting arrows, as shown, on the respective shafts.

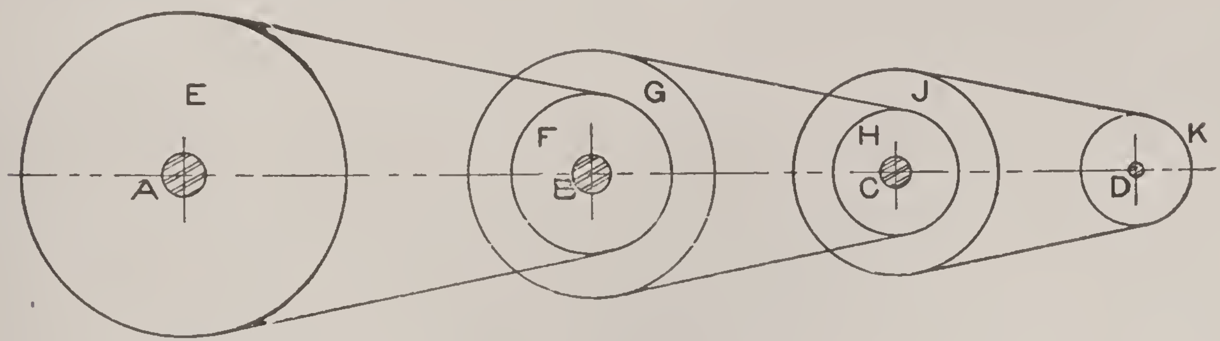


Fig. 65.

Idle Gear. In Fig. 67, gear E drives gear F, and F drives G, that is, F is both a driven and driving gear. Let E have 25 teeth, F 30 teeth, and G 50 teeth, and let shaft C make 100 R. P. M. Then from the rule given above,

$$\text{R. P. M. of A} = 100 \times \tfrac{25}{30} \times \tfrac{30}{50}.$$

In this equation the number of teeth of F (30) occurs both in

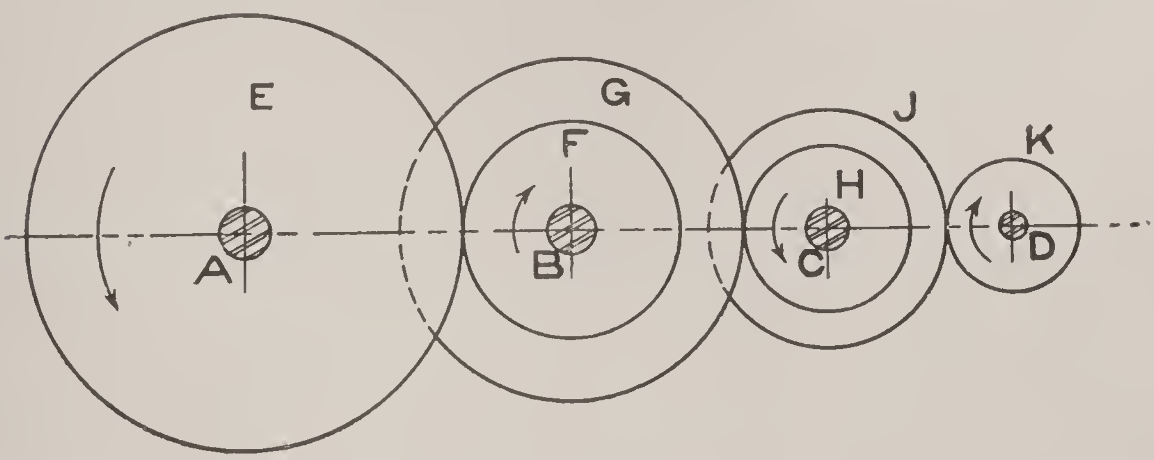


Fig. 66.

the numerator and denominator of the fraction, and will therefore cancel each other, so that the equation becomes

$$\text{R. P. M. of A} = 100 \times \tfrac{25}{50}.$$

Therefore, the speed of A depends only upon the number of teeth in E and G. Gear F is called an idle gear or idler. It should be noticed, however, that A will turn in the opposite direction from what it would if G geared directly with E.

In any train of wheels, the number of turns of the last wheel

(as K in Figs. 65 and 66, or G in Fig. 67) divided by the number of turns of the first wheel, as E, is called VALUE OF THE TRAIN. Considering this statement in connection with formula (20) we have the following:—

$$\text{Value of train} = \frac{\text{Product of teeth of all drivers}}{\text{Product of teeth of all driven wheels.}} \qquad (21)$$

This value will be positive or negative, that is, it will have the algebraic sign + or — before it, according as the last wheel turns in the same direction as the first, or in the opposite direction.

Epicyclic Trains. In Fig. 68 the gear B is loose on the shaft H and driven by the gear E; arm A is keyed to the shaft H so that it turns when the shaft turns. Gears C and D are carried on studs on the arm. It will be evident that if B and H are caused

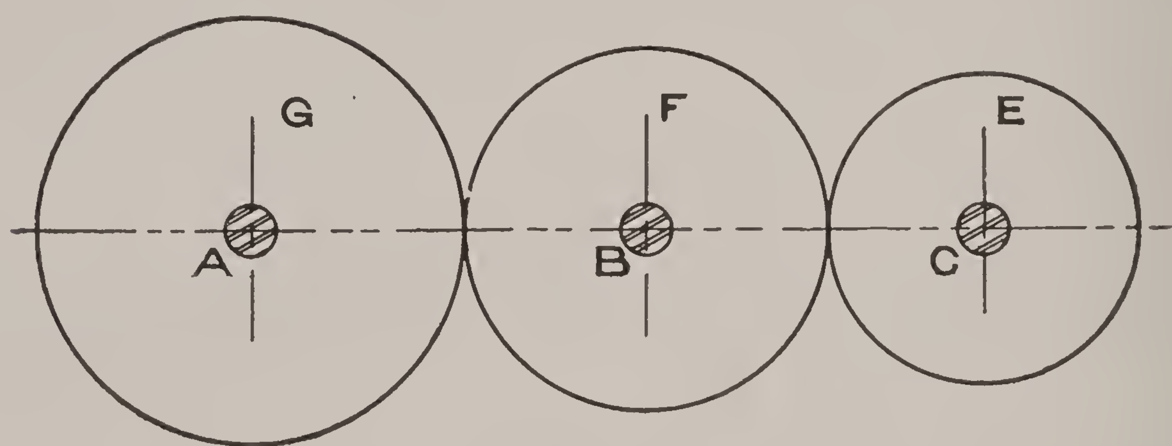


Fig. 67.

to turn independently, the gear D will have a different number of turns on its own axis from what it would if A were fixed and D were driven directly through the train BCD.

In the following formula, the value of the train is the ratio of the turns of D to the turns of B if the arm were fixed, considering B the first wheel and D the last; by the turns of B and D respectively we mean the actual number of turns they make when the arm is in motion. The formula by which the turns of A, B, or D can be found is as follows,—

$$\text{Value of train} = \frac{\text{Turns of last wheel} - \text{turns of arm}}{\text{Turns of first wheel} - \text{turns of arm}} \qquad (22)$$

This can be easily proved, but the proof need not be studied to understand the use of the formula. In applying this, the proper algebraic signs must be given to the value of the train, and the

turns of the arm: That is, if with the arm fixed, B and D would turn in the same direction, the value of the train is considered plus, if in opposite directions, the value of the train is minus. If the arm turns in the same direction as B, the turns of the arm would be plus, but if in the opposite direction the turns of the arm would be minus, so that the formula would become,

$$\text{Value of train} = \frac{\text{Turns of last wheel} + \text{turns of arm}}{\text{Turns of first wheel} + \text{turns of arm}}$$

That is, two minus signs before the number of turns of arm would make it plus. This may be more clearly understood from a study of the following problems:

In Fig. 68 let B have 75 teeth, C 30 teeth and D 25 teeth, and let B be driven by E at a speed of 20 R. P. M. right-handed,

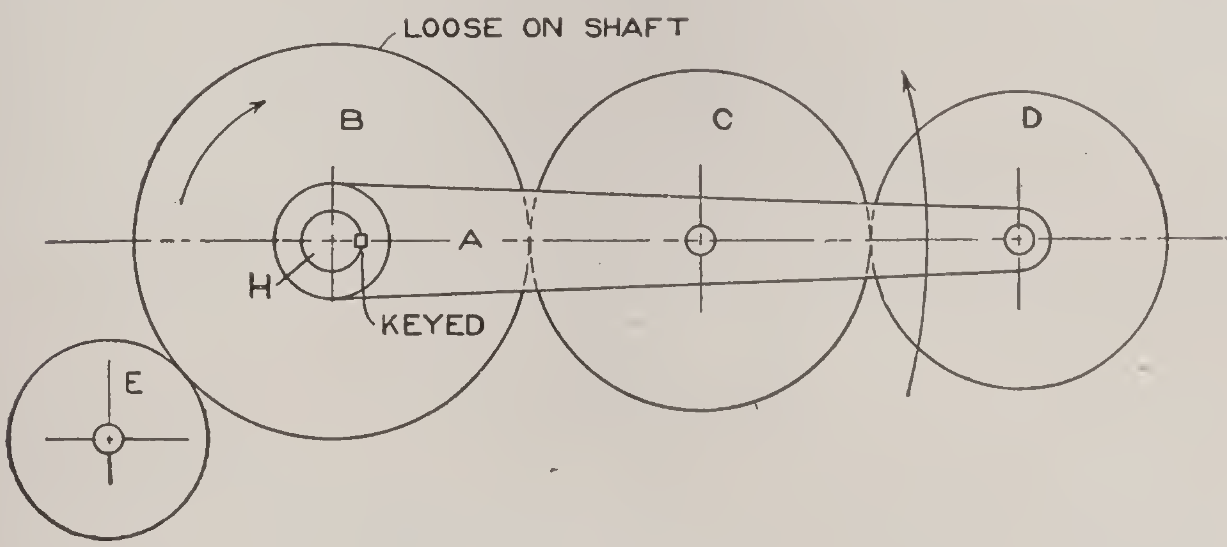


Fig. 68.

while A is driven at a speed of 2 R. P. M left-handed, to find the number of R. P. M. of D and the direction in which it will turn. We will use formula (22). The value of the train will be found from formula (21).

$$\text{Value of train} = \frac{\text{Teeth of B} \times \text{Teeth of C}}{\text{Teeth of C} \times \text{Teeth of D}}$$

$$\text{Value of train} = \tfrac{75}{30} \times \tfrac{30}{25} = 3$$

and since with the arm fixed B and D would turn in the same direction, the value of the train will be plus. Since the arm A turns in the opposite direction from B, its number of turns will have a minus sign. Then substituting the formula (22.)

$$3 = \frac{\text{R. P. M. of D} - (-2)}{20 - (-2)} = \frac{\text{R. P. M. of D} + 2}{20 + 2}$$

or

$$3 \times 22 = \text{R. P. M. of D} + 2$$

whence

$$64 = \text{R. P. M. of D}$$

In Fig. 69 the gear B, the arm A, and the annular gear D have a common axis, but are arranged to turn independently of each other about this axis. C is an idle wheel connecting B with the annular gear D and is on an axis carried by A. Let B have 30 teeth, C 45 teeth and D 120 teeth, and let B be caused to have 125 R. P. M. right-handed and arm A have 75 R. P. M. left-handed, to find the number of turns and direction of motion of D. First

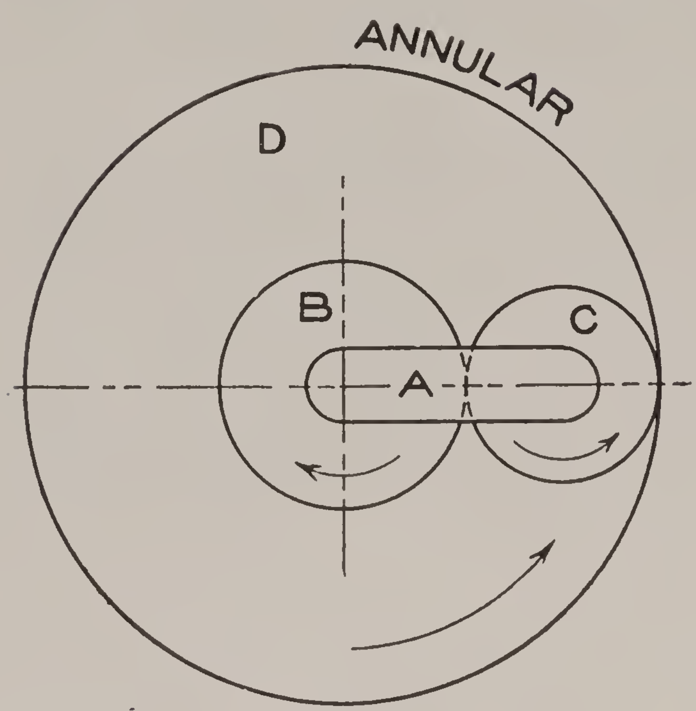


Fig. 69.

find the value of the train if A were fixed, which would be

$$\frac{(30 \times 45)}{(45 \times 120)} = \frac{1}{4}$$

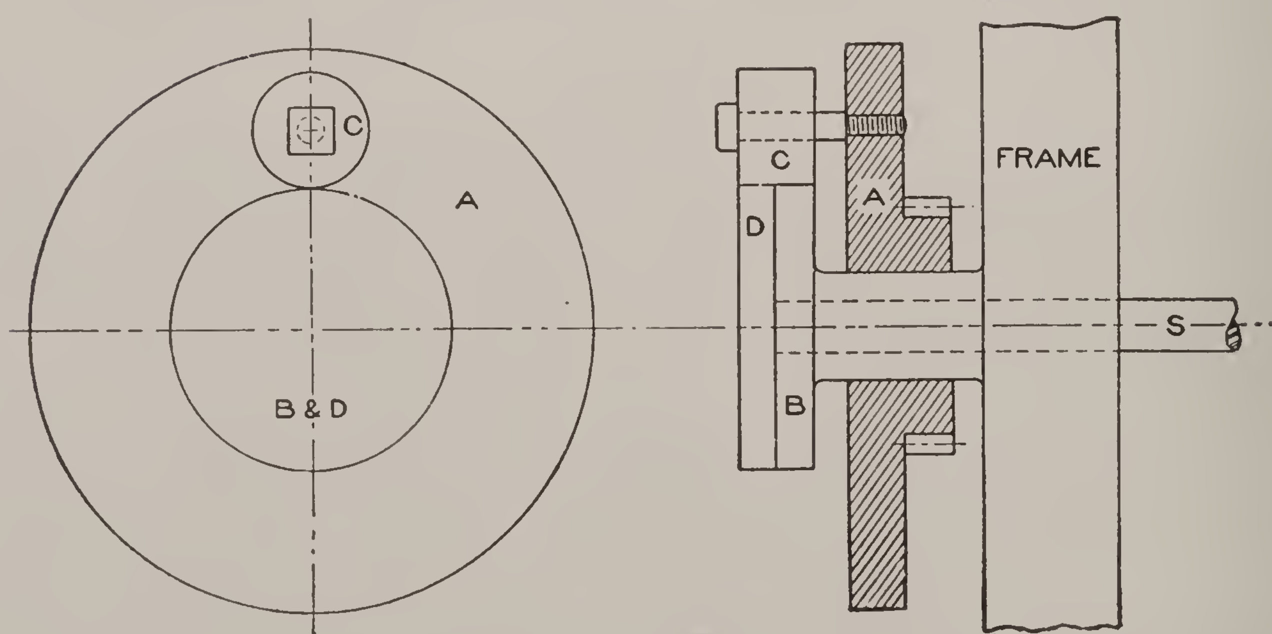


Fig. 70.

thence substituting in formula (22).

$$-\frac{1}{4} = \frac{\text{Turns of D} - (-75)}{125 - (-75)} = \frac{\text{Turns of D} + 75}{200}$$

$$\text{whence turns of D} = -125$$

that is D, makes 125 R. P. M. in the opposite direction from that in which B is turning.

In Fig. 70, gears B and D have a common axis, B is fast to the frame of a machine, D is fast to the shaft S, which drives the work on the machine, A is a disc centered on the hub which supports B, and driven by a gear (not shown) which meshes with a gear on the back of A. C is a gear carried on the stud in A. The gear B corresponds to the first wheel or driver of an epicyclic train, A to the arm, C is an idle wheel, and D is the last wheel of the train. B has one tooth more than D. Let B have 35 teeth, C 15 teeth, D 34 teeth, and let A make one turn right-handed, to find the speed of D and the direction of its motion. The value of the train, considering A fixed and B the driver, is $\frac{35}{34}$. Then formula (22).

$$\frac{35}{34} = \frac{\text{Turns of D} - 1}{0 - 1}$$

$$\text{or } -35 = 34 \text{ Turns of D} - 34$$

$$-1 = 34 \text{ Turns of D}$$

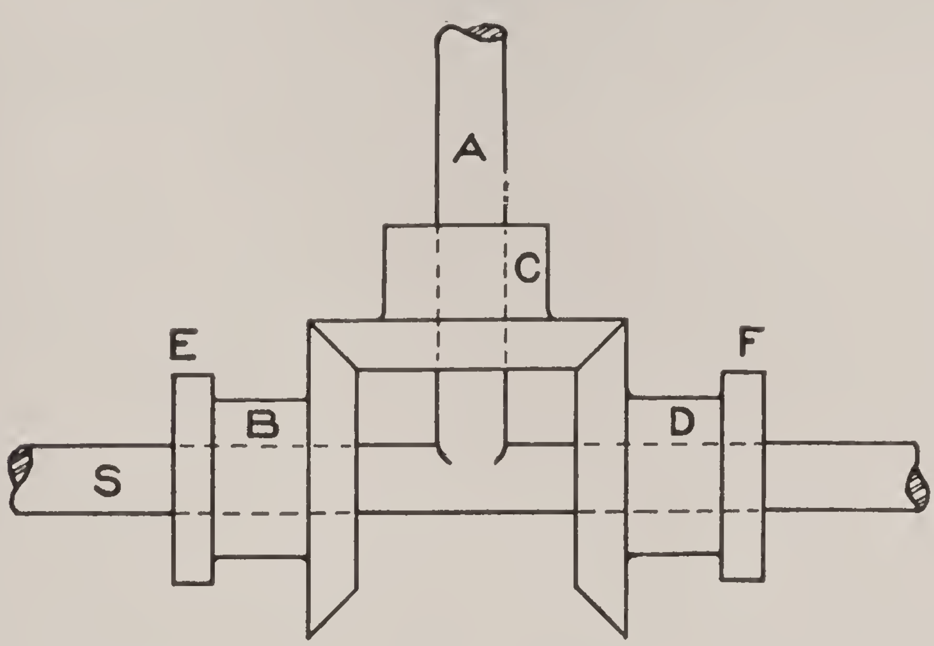


Fig. 71.

or Turns of D $= -\frac{1}{34}$. That is, for one turn of A right-handed, with B fixed, D makes $\frac{1}{34}$ of a turn left-handed.

In Fig. 71 is shown an epicyclic train of bevel gears. The shaft S carries the shaft A either welded to it or clamped on it in some way. Loose on S are the bevel gears B and D, held in place by collars (not shown) and loose on A is the bevel C, gearing with each of the others. Fast to B is the spur gear E, which is driven from some source of power not shown. S is driven from

some external source of power, thus causing the arm A to swing around. Let all of the bevels have the same number of teeth, and let B be driven at a speed of 50 R. P. M. right-handed, and S at a speed of 25 R. P. M. right-handed, to find the speed and direction of D. Formula (22) applies here as in other cases which we have considered.

$$\text{The value of the train} = -1$$

$$\text{Then } -1 = \frac{\text{Turns of D} - 25}{50 - 25}$$

$$-25 = \text{Turns of D} - 25.$$

$$\text{Therefore, Turns of D} = 0.$$

Again let B turn 50 R. P. M. right-handed, to find the direction and number of turns of A in order that D shall turn 25 R. P. M. left-handed.

$$-1 = \frac{-25 - \text{Turns of A}}{50 - \text{Turns of A}}$$

$$-50 + \text{Turns of A} = -25 - \text{Turns of A}.$$

$$\text{Therefore, Turns of A} = 12\tfrac{1}{2} \text{ right-handed.}$$

EXAMINATION PAPER

MECHANISM.

Read carefully: Place your name and full address at the head of the paper. Any cheap light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper: use your own words, so that we may be sure that you understand the subject.* After completing the work add and sign the following statement:

I hereby certify that the above work is entirely my own.

(Signed)

1. An engine makes 280 revolutions per minute. If the stroke is 16 inches, what is the linear velocity of the crank pin in feet per second?

2. The pitch of a jack screw is $\frac{1}{4}$ inch. The length of the bar is 4 feet. What weight can be lifted if the force applied at the end of the bar is 148 pounds?

3. A worm of double thread meshes with a worm wheel having 64 teeth. How many revolutions per minute must the worm have to turn the wheel 2 times per minute?

4. A lever safety valve has a lever 30 inches long. The weight hung on the end weighs 24 pounds. If the valve is $4\frac{1}{2}$ inches from the fulcrum and has an area of $3\frac{1}{4}$ square inches, at what pressure per square inch will it blow off?

   Neglect weight of valve, spindle and lever.

5. Define circular pitch. Diametral pitch.

6. If a gear has 20 teeth and it is 6 pitch, how far will the rack move in $2\frac{1}{2}$ revolutions of the gear?

7. Find the piston speed in feet per minute of an engine making 5.4 revolutions per second, the stroke being 18 inches.

8. Two gears mesh with each other. They are 8 pitch. If they have 40 teeth and 68 teeth, respectively, what are the diameters and how far apart should the centers of the shafts be placed?

9. The pitch circle of an annular gear is 36 inches in diameter. The spur gear meshing with it is 8 pitch and has 24 teeth. How many revolutions must the spur gear make to turn the annular gear 13 times per minute?

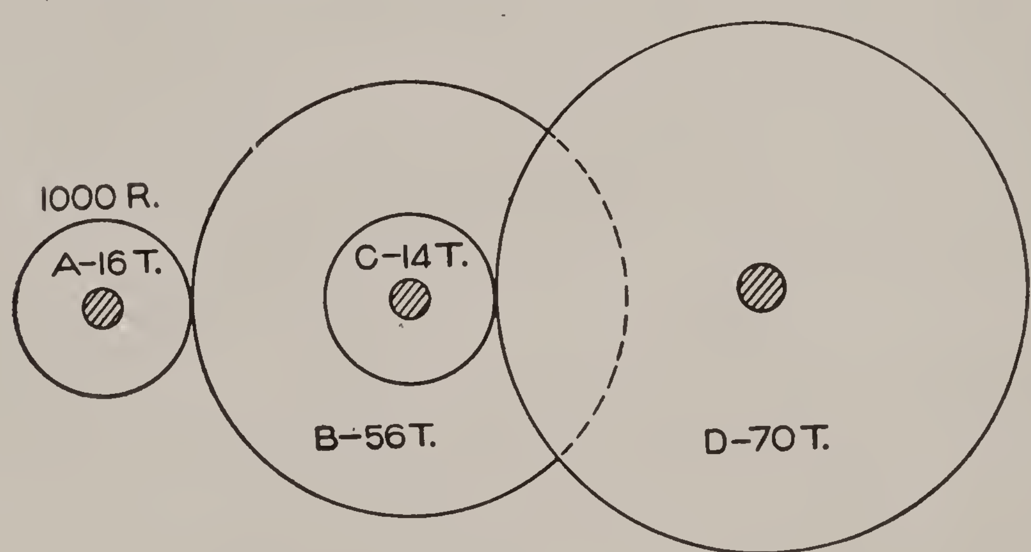
10. A lever is 26 inches long. A weight of 20 pounds is hung on one end. The distance of this weight from the fulcrum is 11 inches. What power will be necessary to raise the weight if the distance from the fulcrum to the power is 15 inches?

11. Describe the eccentric and eccentric-rod linkage.

12. A worm of single thread is in mesh with a worm wheel having 36 teeth. A crank of 16 inches radius is attached to the worm and a drum 10 inches in diameter is fastened to the worm wheel. How fast will the weight rise if the crank is turned 40 times per minute?

13. Suppose the press shown in Fig. 32, page 31, has a hand wheel 16 inches in diameter. The pitch $P = \frac{1}{4}$ inch and pitch $p = \frac{1}{5}$ inch. If 80,000 pounds pressure is to be exerted, what force must be applied to the hand wheel?

14. Describe some form of friction clutch.



15. In the train of gears shown, A is attached to the shaft of a motor and makes 1,000 revolutions per minute. How many revolutions per minute will gear D make?

16. If the linear velocity of the rim of a fly wheel is limited to a mile a minute, how many revolutions are allowable if the fly wheel is $7\frac{1}{2}$ feet in diameter?

17. A locomotive is running at the rate of 50 miles per hour. The drivers are 6 feet in diameter and the linear velocity of the crank pin is 24.44 feet per second. What is the length of stroke?

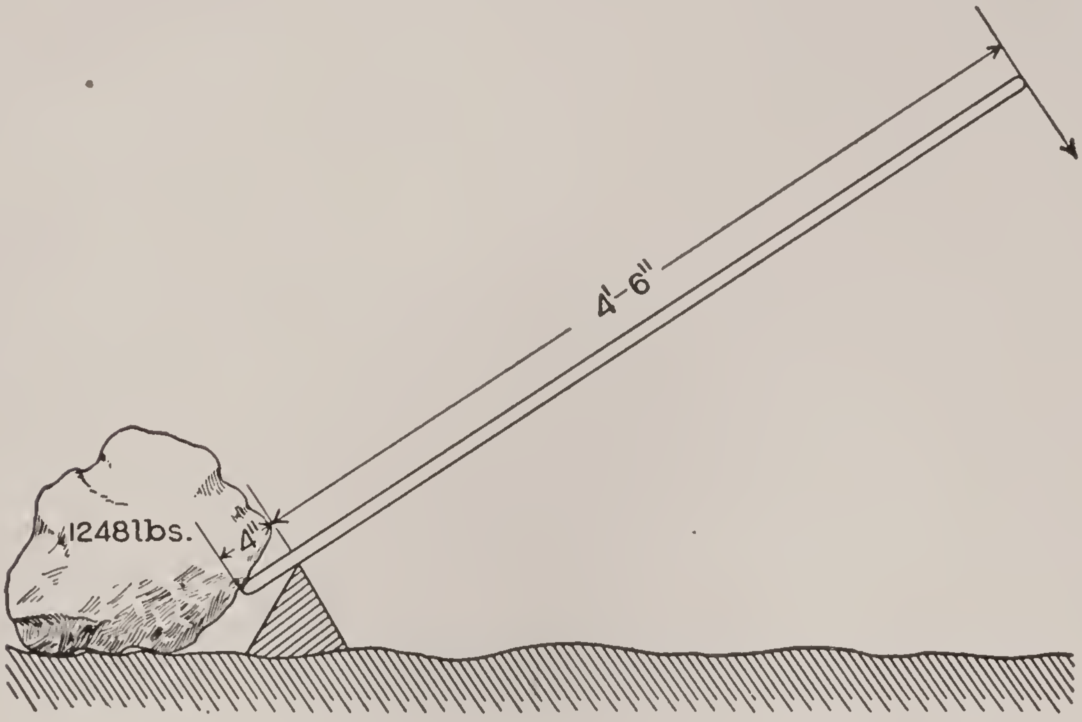
NOTE. The stroke=the diameter of crank-pin circle.

18. What is the pitch of a screw that advances 3 inches in 24 revolutions?

19. What weight can be raised by the device described in question 12 if the force applied to the crank is 110 pounds?

20. In the accompanying sketch, the large stone weighs 1,248 pounds. What force must be exerted at the end of the lever to move the stone?

NOTE. Assume that 40 per cent of the force necessary to lift the stone will move it.



21. If a gear has 48 teeth and the diameter of the pitch circle is 16 inches, what is the circular pitch? What is the diametral pitch?

22. A gear has 16 teeth and runs 800 revolutions per minute. How fast will a gear meshing with it run if it has 56 teeth?

23. The two sprocket wheels of a bicycle have 8 and 24 teeth, respectively. If the wheels are 28 inches in diameter, how many times must the pedals turn while the bicycle is going one mile?

24. In the above example, how many turns per minute must the pedals make if the bicycle moves at a velocity of a mile in 58 seconds?

25. What is pitch diameter?

26. If motion is desired along a shaft as well as at right angles to a shaft, what kind of cam must be used?

27. Two pulleys are connected by a leather belt. The driver is keyed to a shaft making 80 revolutions per minute, and is 34 inches in diameter. How many revolutions will the driven pulley make if it is 14 inches in diameter?

28. To what class does the lever of the lever safety valve belong?

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